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V/STOL AIRCRAFT DESIGN SENSITIVITY TO FLYING QUALITIES CRITERIA--ETC(U)
FEB 80 B B BRASSELL, R L FORTENBAUGH N62269-78-C-0177
UNCLASSIFIED NADC-77337-60 NL

1 of 3

LEVEL II

12

UNCLASSIFED
REPORT NO. NADC-77337-60

AD A105783

V/STOL AIRCRAFT DESIGN SENSITIVITY TO FLYING QUALITIES CRITERIA

Billy B. Brassell, Jr.
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VOUGHT CORPORATION
DALLAS, TEXAS

28 February 1980

Final Report

AIRTASK No. WF 41-400-000

Approved for Public Release; Distribution Unlimited

Prepared for:

Naval Air Development Center
Warminster, PA 18974

Contract No. N62269-78-C-0177

10 19

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: NADC 77337-60

2. GOVT ACCESSION NO.: AD-A105783

3. RECIPIENT'S CATALOG NUMBER:

4. TITLE (and Subtitle): V/STOL Aircraft Design Sensitivity to Flying Qualities Criteria,

5. TYPE OF REPORT & PERIOD COVERED: Final Report.

6. PERFORMING ORG. REPORT NUMBER:

7. AUTHOR(s):

Billy B. Brassell, Jr.
George C. Booth
Robert L. Fortenbaugh

8. CONTRACT OR GRANT NUMBER(s): F41400

9. PERFORMING ORGANIZATION NAME AND ADDRESS:

Vought Corporation
P.O. Box 225907
Dallas, TX 75265

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: PE 62241, WF 41400

11. CONTROLLING OFFICE NAME AND ADDRESS:
Naval Air Development Center
Code 6053
Warminster, PA 18974

12. REPORT DATE: 28 Febr[redacted]980

13. NUMBER OF PAGES:

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): N62269-78-C-0107

15. SECURITY CLASS. (of this report): UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report):

Approved for Public Release; Distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):

18. SUPPLEMENTARY NOTES:

19. KEY WORDS (Continue on reverse side if necessary and identify by block number):

VSTOL Aircraft, Flying Qualities, Design Sensitivity

20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

Preliminary designs were developed for four generically different V/STOL airplane concepts. Two of the airplanes used lift/cruise fans and were designed to satisfy high altitude, subsonic Anti-Submarine Warfare (ASW) mission requirements. The other two airplanes used different jet lift and lift/cruise propulsion concepts and were designed for supersonic, Deck Launched Intercept (DLI) mission requirements. The sensitivities of each airplane to provisions for flying qualities were evaluated and were related to selected flying

qualities characteristics.

The study outlines a procedure or methodology that can be followed in future studies for assessing design sensitivity to flying qualities. The assessment procedure can be relatively simple in hover and cruise flight regimes, but may require extensive analysis in forward flight and transition flight regimes. Generally design sensitivities were found to be configuration specific, since takeoff gross weight sensitivity to thrust margin and propulsion control provisions can vary among different types of propulsion systems. Mission sensitivities were less variant between airplanes designed for similar missions. Design sensitivities to hover control power were by far the most significant to V/STOL design, and support a high priority need for satisfactory VTOL control power criteria.

FOREWORD

The work described in this report was sponsored by the Flight Dynamics Branch of the Aircraft and Crew Systems Technology Directorate of the Naval Air Development Center. Mr. Carmen J. Mazza served as technical monitor and program manager for the Naval Air Development Center. Mr. Billy B. Brassell, Jr. was principal investigator for Vought Corporation.

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1.0 SUMMARY

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The study outlines a procedure or methodology that can be followed in future studies for assessing design sensitivity to flying qualities. The assessment procedure can be relatively simple in hover and cruise flight regimes, but may require extensive analysis in forward flight and transition flight regimes. Generally design sensitivities were found to be configuration specific, since takeoff gross weight sensitivity to thrust margin and propulsion control provisions can vary among different types of propulsion systems. Mission sensitivities were less variant between airplanes designed for similar missions. Design sensitivities to hover control power were by far the most significant to V/STOL design, and support a high priority need for satisfactory VTOL control power criteria.

2.0 INTRODUCTION

2.1 Background

The general purpose of this study was to investigate the sensitivity of V/STOL airplane design to flying qualities requirements. A need for such a study had been identified by the V/STOL Technology Assessment Committee (VTAC) in reference 1. VTAC recommended that this study focus on the "sensitivities of V/STOL aircraft design to... stability and control parameters" and follow an approach similar to that of Sattler and Sherrieb in reference 4. Sattler and Sherrieb evaluated design sensitivities of nine airplanes to thirty-four technology topics, but only three topics were related to stability and control parameters.

A key purpose of this study was to support the continuing development of flying qualities criteria. The VTAC report cited a "dire need of sensible V/STOL flying qualities design guidance." Two recent studies (references 5, 6, and 7; and 15) also resulting from VTAC recommendations have provided significant contributions to developing better criteria for Navy V/STOL requirements. Further efforts will undoubtedly continue to expand and improve from these results. Relative to sensible design guidance, new criteria should avoid arbitrary forms, interpretations, or types that may unnecessarily penalize a design concept. To this end, consideration of design sensitivity should support continuing criteria development and result in better guidance for future designs.

2.2 General Objective

The objective of this study was to evaluate four generically different V/STOL airplane concepts to determine the sensitivity of each airplane design to flying qualities requirements.

2.3 General Approach

A flow chart outlining the study approach is presented in figure 1. Initial activity involved the selection of airplane concepts, design missions, and sizing criteria. Four airplanes, two subsonic and two supersonic, were selected to include a range of potential aerodynamic and propulsion system concepts. Typical requirements and performance constraints were selected for a subsonic, high altitude ASW mission and a supersonic, DLI mission.

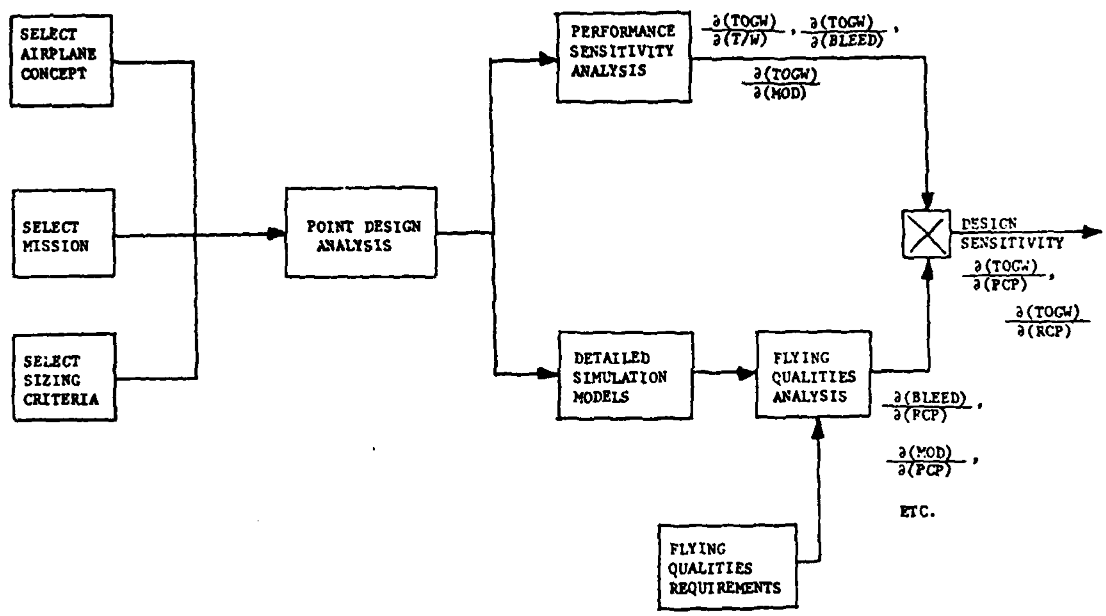


Figure 1. Study Flow Chart

Airplane point designs were developed to meet the design mission requirements and performance criteria. Following definition of the point designs the study took two paths. One path developed design and performance sensitivities of TOGW and mission parameters to variations in design parameters. The other path developed the sensitivity of design parameters to flying qualities parameters and criteria. The final step was to combine the two sets of sensitivity relations to obtain design sensitivity to flying qualities.

The design and performance sensitivity path generated the sensitivity of each design to thrust-to-weight margin, propulsion control provisions for attitude control, and selected configuration changes. These sensitivities were defined in two forms. The first is design sensitivity, which provides several point design aircraft of different takeoff gross weights (TOGW) all of which meet mission and sizing criteria. The second is mission sensitivity. For mission sensitivity, the point design is fixed and the effect of design changes on mission performance evaluated.

The flying qualities path required the development of detailed simulation models for each airplane and involved evaluation of the sensitivity of stability and control parameters to design variations. In the flow chart (figure 1), flying qualities requirements are shown as inputs to the analysis. This represents both the selection of criteria for analysis and the evaluation of criteria sensitivity; i.e. the impact of changing the criteria themselves.

The final sensitivity results were obtained by combining the design and performance sensitivities and the flying qualities sensitivities. For example, the sensitivity of TOGW with respect to (w.r.t.) pitch control power required was obtained from the sensitivity of TOGW w.r.t. bleed requirements and the sensitivity of bleed requirements w.r.t. control power requirements.

2.4 Organization of This Report

The remainder of this report is arranged as follows. Section 3 presents a summary of the four airplane designs and defines the ground rules used for their selection. Design missions and design guidelines are also defined.

Section 4 summarizes the flying qualities evaluation. This includes selection of flying qualities criteria that are related to design definition and mission performance. Key flying qualities characteristics of the four airplanes are presented for the hover and low speed, forward flight, and low speed conventional flight regimes.

The basic sensitivity relationships are introduced in Section 5. Design and performance sensitivity results are summarized and compared for the study airplanes. Design sensitivity to interpretations of hover and low speed criteria are also presented as well as mission sensitivity to flying qualities parameters.

Results and conclusions comprise Section 6. Section 7 presents recommendations based on this work.

Four appendices are included in the report. Appendix A contains a summary of the synthesis and selection of the baseline point designs. Appendix B is a compendium of aerodynamic and flying qualities data for the four airplanes. Two key computer routines used in the study are described in the remaining appendices. Appendix C contains a description of the Aircraft Synthesis and Analysis Program (ASAP) used for design synthesis and evaluation of design and performance sensitivities. The OLSIM program used in the flying qualities analysis is described in Appendix D.

3.0 AIRPLANE DESIGN SUMMARY

A desired goal in selection of V/STOL airplane concepts for this study was to span a wide range of propulsion concepts and configuration features for both subsonic and supersonic designs. Groundrules set by the NADC technical monitor eliminated consideration of Vertical Attitude Take Off and Landing (VATOL) concepts, helicopters, tilt propellers, and deflected slipstream concepts. These groundrules also limited airplane selection to concepts with near-term development potential. The four airplane concepts selected within these groundrules were

- Tandem Fan
- Tilt Nacelle, Tandem Wing
- Jet Lift plus Lift/Cruise
- Remote Augmented Lift System (RALS)

Aerodynamic configuration and propulsion system concepts of these airplanes are summarized in Table 1. General arrangement sketches for each airplane are shown in Figures 2 through 5. Propulsion control functions for V/STOL operation are summarized in Table 2 and aerodynamic controls are defined in Table 3.

3.1 Design Missions

The Tandem Fan and Tilt Nacelle airplanes were designed for a subsonic, high altitude ASW mission defined in the Type A RFQ/I (reference 9). The Lift plus Lift/Cruise and the RALS airplanes were designed for a supersonic DLI mission defined in the Sea Based Air Studies (reference 13). Classified details of these missions and related performance requirements are not included in this report.

3.2 Design Synthesis

Synthesis of the four airplane designs was accomplished with the aid of Vought's Aircraft Synthesis and Analysis Program (ASAP). In addition to satisfying the selected missions and related performance requirements, single axis attitude control powers of approximately 1.5, 1.0, and 0.5 rad/sec^2 were provided in the roll, pitch, and yaw axes, respectively. These control power levels were selected simply as a representative point of departure for subsequent sensitivity analysis. Each baseline design was defined with a vertical takeoff thrust-to-weight ratio (T/W) of 1.05 with no special provisions for operation with an engine failed. The single exception was vertical takeoff T/W for the RALS airplane, where control power requirements dictated a T/W of 1.14.

Key geometrical data and mass properties of the baseline design selections are summarized in Table 4. More detailed discussion of the synthesis of each design selection is given in Appendix A.

TABLE 1
SUMMARY OF AERODYNAMIC AND PROPULSION SYSTEM CONCEPTS

AIRPLANE	AERODYNAMIC CONCEPT	PROPULSION CONCEPT
Tandem Fan	Conventional wing-horizontal tail, single vertical, sub-sonic	Medium disc loading, fans, 4-poster
Tilt Nacelle	Tandem wing, single vertical, subsonic	Medium disc loading, fans, 2-poster
Lift + Lift/Cruise	Conventional wing-horizontal tail, twin verticals, supersonic	High disc loading, jet lift plus lift/cruise
RALS	Delta-canard single vertical, supersonic	High disc loading, remote auxiliary lift system

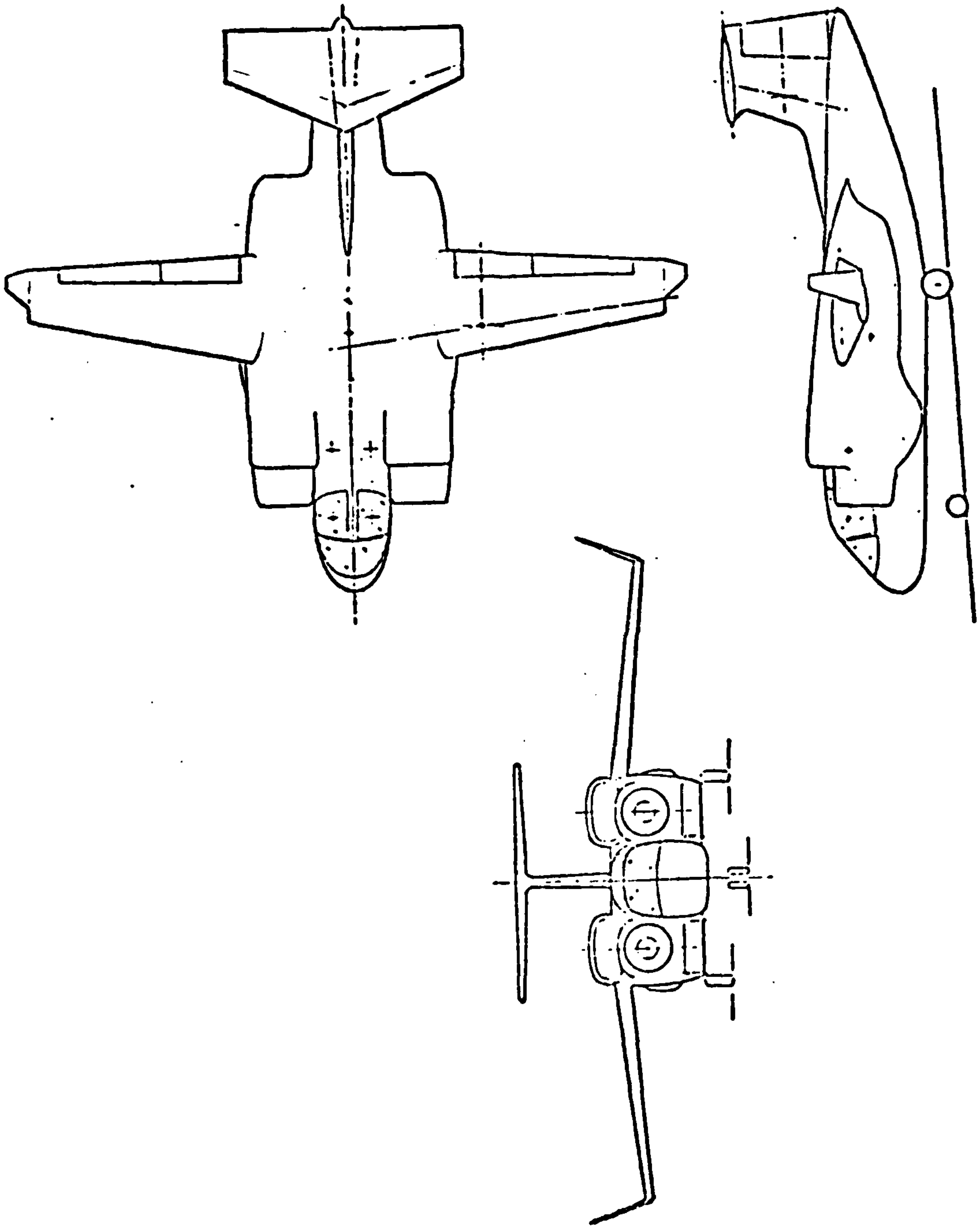


Figure 2. Tandem Fan General Arrangement

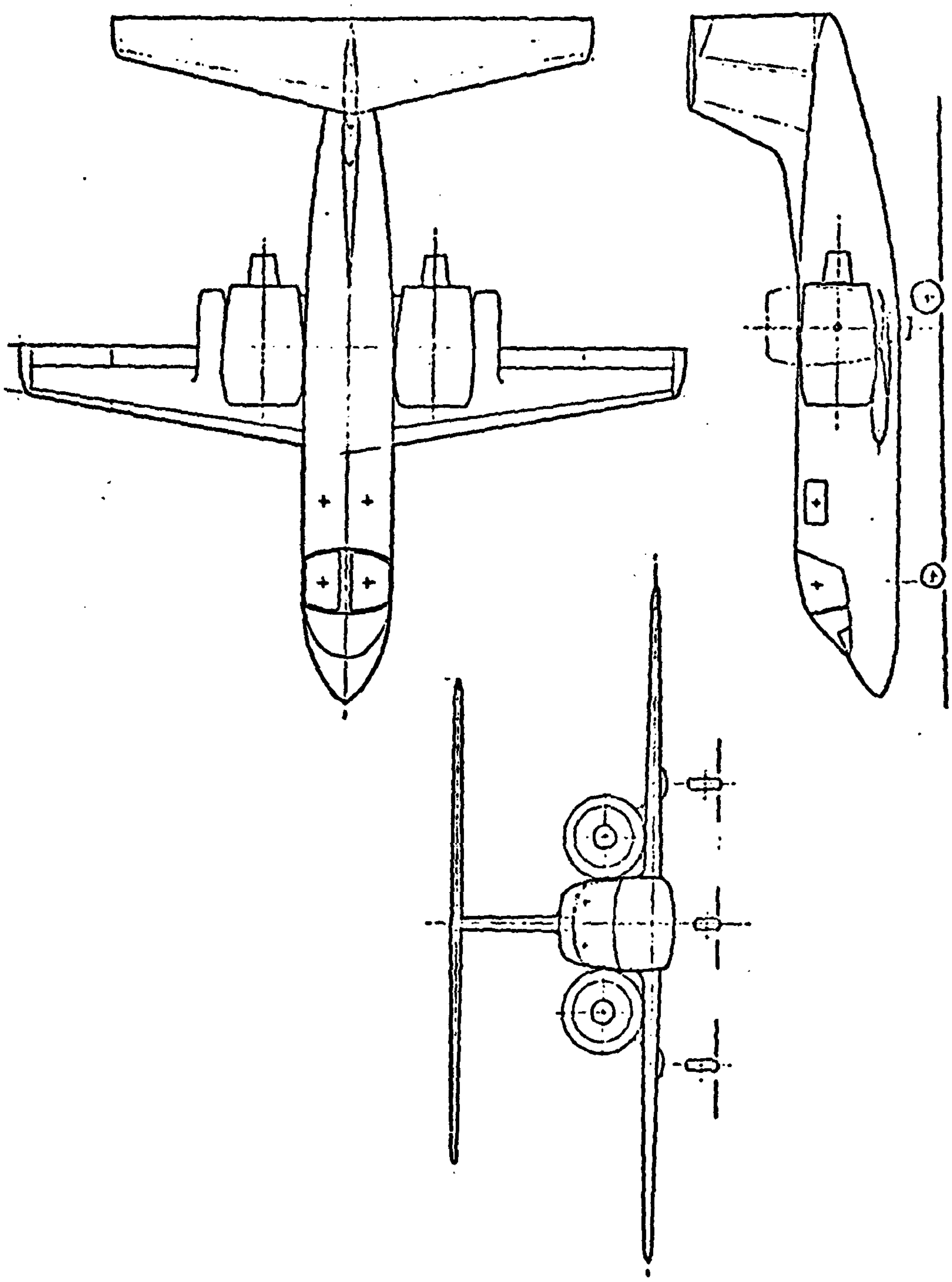


Figure 3. Tilt Nacelle Airplane General Arrangement

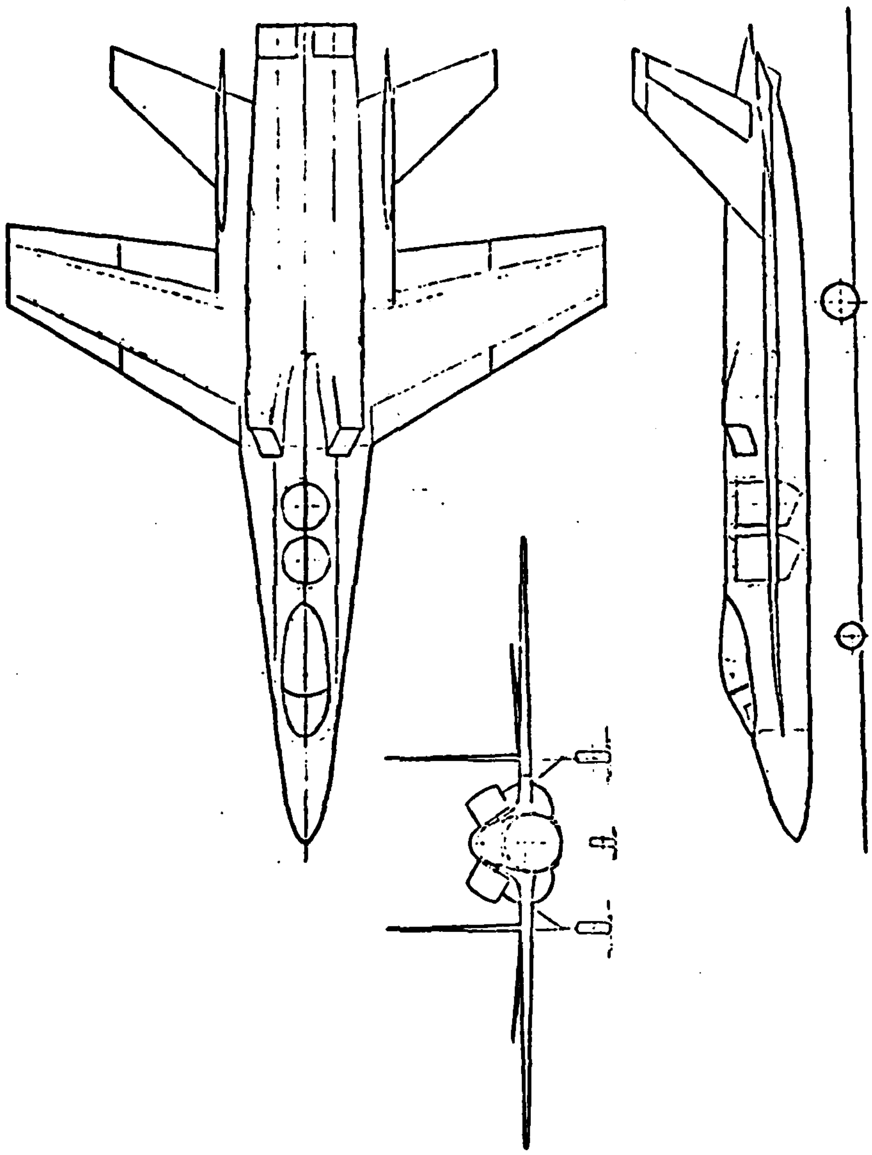


Figure 4. Lift + Lift/Cruise Airplane General Arrangement

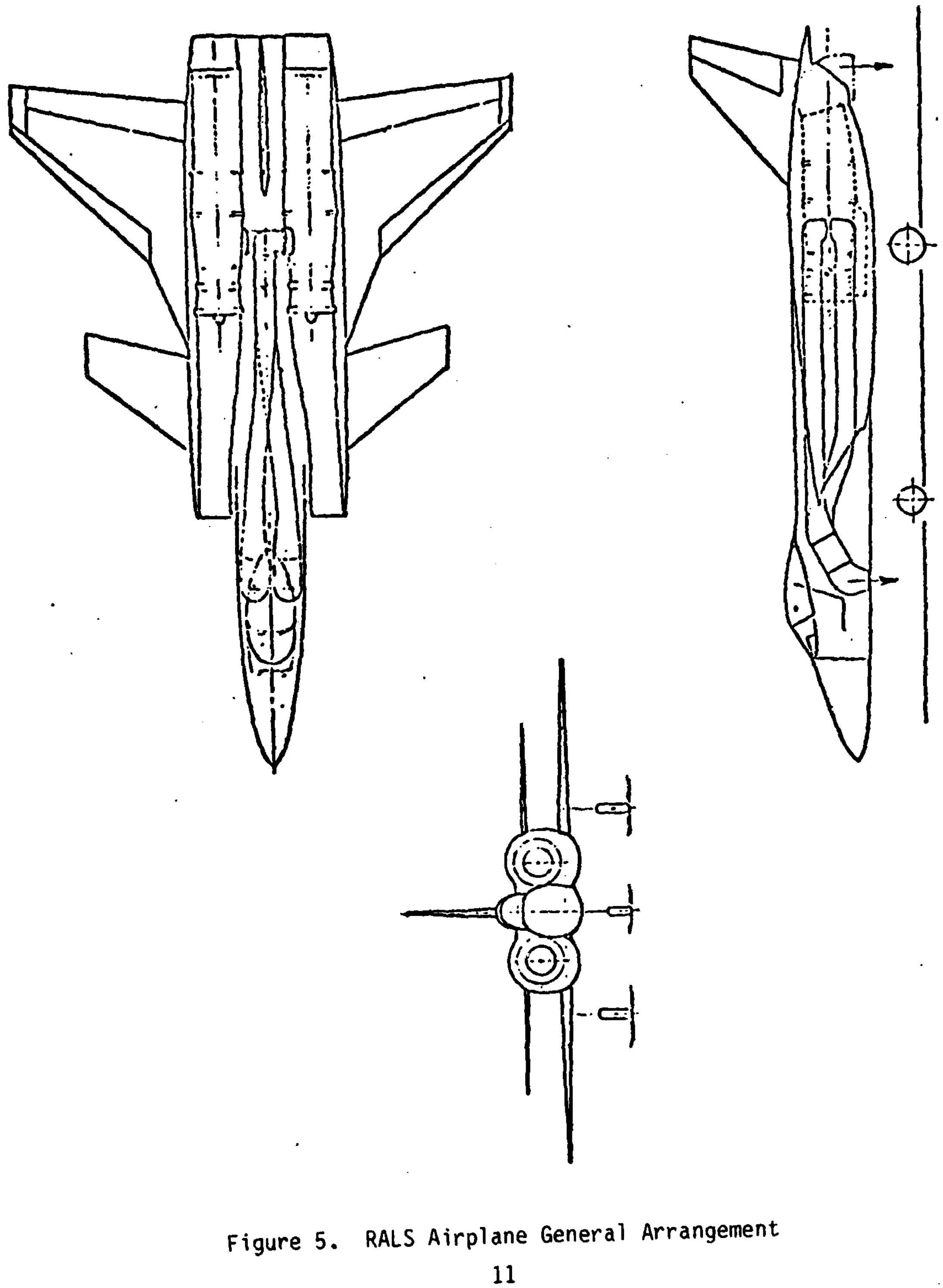


Figure 5. RALS Airplane General Arrangement

TABLE 2

SUMMARY OF PROPULSION CONTROL PROVISIONS

CONTROL \ A/P	TANDEM FAN	TILT NACELLE	LIFT + LIFT/CRUISE (LIFT ENGINE BLEED)	RALS
Pitch	Differential Fore/Aft Fan Thrust Modulation with VIGV	Differential Fore/Aft Reaction Jets	Differential Fore/Aft Reaction Jets*	Differential RALS/ADEN Thrust Modulation
Roll	Differential Left/Right Fan Thrust Modulation with VIGV	Differential Left/Right Fan Thrust Modulation with VIGV	Wing Tip Reaction Jets*	Wing Tip Reaction Jets*
Yaw	Differential Longitudinal Nozzle Deflection	Differential Longitudinal Nozzle Deflection	Differential Lateral Thrust Vectoring (L + L/C Thrust)	Differential Lateral Vectoring (RALS & ADEN Thrusts)
Height	Collective VIGV + Fan Speed Modulation	Collective VIGV + Fan Speed Modulation	Collective L+L/C Thrust Modulation	Collective Thrust Modulation (RALS & ADEN)
Fore & Aft	Longitudinal Thrust with All nozzles	Nacelle Position	Longtudinal Thrust Vectoring with L & L/C nozzles	Longitudinal Thrust Vectoring (RALS & ADEN)

*Reaction thrust does not contribute to lift

TABLE 3

AERODYNAMIC CONTROLS SUMMARY

	AIRPLANE			
Control Function	Tandem Fan	Tilt Nacelle	L + L/C	RALS
Pitch	All moving horizontal tail	Elevator	All moving horizontal tail	Elevons
Roll	Flaperons	Flaperons	Flaperons	Flaperons
Yaw	Rudder	Rudder	Rudder	Rudder

TABLE 4
SUMMARY COMPARISON OF POINT DESIGN SELECTIONS

AIRPLANE	TANDEM FAN	TILT NACELLE	L + L/C	RALS
TOGW, lb	40,954	43,607	42,163	46,904
WEIGHT EMPTY, lb	25,556	26,868	24,560	27,913
WING AR	7	7	4	2.8
WING, AREA, ft^2	450	358/219 (1)	377	426
WING LOADING (TO), lb/ft^2	91	76 (2)	112	110
TAKEOFF T/W	1.05	1.05	1.05	1.14 (3)
FAN DIAM, inches	45.7	66.0	-	-
VTO THRUST SPLIT, %	48/52	-	60/40	41/59

NOTES: (1) FORWARD/AFT "WINGS"

(2) BASED ON TOTAL AREA OF BOTH WINGS

(3) PROVISION OF PITCH CONTROL REQUIRED 1.14 T/W; THEREFORE THE HIGHER T/W (1.14 VICE 1.05) WAS USED.

4.0 FLYING QUALITIES EVALUATION

Stability and control characteristics of the four baseline airplanes were estimated in flight regimes from hover to low speed cruise flight. These basic characteristics included trim requirements, stability and control derivatives, and modal characteristics which were evaluated with the aid of a detailed simulation model of each airplane. Comparisons of these characteristics between the four airplanes as well as comparisons to selected criteria from MIL-F-83300 and MIL-F-8785B are summarized in this Section. This summary was drawn from the more detailed definition of aerodynamic data and basic stability and control characteristics presented in Appendix B.

4.1 Flying Qualities Criteria

The flying qualities requirements of MIL-F-83300 and MIL-F-8785B were screened to identify those requirements that could be related directly to design selection and mission performance. The key requirements selected are summarized in Table 5.

The hover and low speed requirements represent the key criteria in MIL-F-83300 for provision of thrust and attitude control margins for trim and dynamic response. *These criteria are not necessarily sufficient for defining* total control power provisions, since they are stated in the form of control margins. Other factors, such as the operational environment, may influence total control power provisions. Recent flight simulation results from the V/STOL Flight Control/Flying Qualities Study (reference 6) have indicated the sensitivity of control power requirements to the type of flight control system and the operational goal for landing operations from small ships (DD-963 class).

In addition to the hover and low speed requirements, the longitudinal and lateral-directional modal criteria (paragraphs 3.3.2 and 3.3.7) were selected from the "Forward Flight" section of MIL-F-83300. These particular requirements represent the primary criteria in this flight regime that could be quantified. Only basic airplane modal characteristics were evaluated, since these characteristics represent the point of departure for determining the degree of control augmentation and the type of control system required. Sensitivity of basic modal characteristics to airplane configuration changes could be an important consideration if unaugmented characteristics were desired to satisfy some minimum (Level 3) criteria.

TABLE 5
SELECTED FLYING QUALITIES CRITERIA

MIL-F-83300

3.2 Hover and Low Speed

3.2.1	Equilibrium Characteristics (3.2.1.1)
3.2.2	Dynamic Response Requirements
3.2.3.1	Control Power (Simultaneous Control Remaining)
3.2.5.1	Height Control Power

3.3 Forward Flight

3.3.2	Longitudinal Dynamic Response (Level 3)
3.3.7	Lateral - Directional Characteristics

MIL-F-8785B

3.2 Longitudinal Flying Qualities

3.2.2.1	Short Period Response

3.3 Lateral - Directional Flying Qualities

3.3.1	Lateral Directional Mode Characteristics

In the conventional airplane flight regime covered by MIL-F-8785B, criteria for longitudinal and lateral-directional modal characteristics were again selected.

4.2 Flying Qualities Evaluation Method

Simulation models representing aerodynamics, inlet ram effects, thrust (exhaust) induced effects, and direct thrust contributions to forces and moments were assembled for each airplane. Basic aerodynamic data estimated from reference 11 were incorporated into the general V/STOL model of Clark (reference 14) to provide continuous representation of aerodynamic characteristics through angles of attack of $\pm 180^0$ and sideslip of $\pm 90^0$. Inlet ram forces and moments were estimated and resolved by means of a generalized model given in reference 12. Thrust induced effects were included in the longitudinal axes only, since methods for estimating lateral and directional effects were not available.

The simulation models were then incorporated into Vought's OLSIM computer routine (Appendix D) for evaluations of trim requirements, stability and control derivatives, and basic modal dynamics. These evaluations included hover station keeping in winds from various directions; level, climbing and descending forward flight for different attitudes; and conventional, low speed aerodynamic flight conditions. Lack of Mach number and aeroelastic effects in the models precluded more extensive cruise flight evaluations.

4.3 Estimated Flying Qualities of Baseline Aircraft

A summary of key flying qualities characteristics of the four airplanes is presented for the hover and low speed, forward flight, and cruise flight regimes. Additional characteristics for each airplane are presented in Appendix B.

4.3.1 Hover and Low Speed Characteristics

Control power required to trim in a wind was evaluated for the four airplanes. Figure 6 presents a summary of the hover in a 35 kt wind trim analysis. A wind direction of 180 degrees is a headwind and a 90 degree wind is directed into the port side of the airplane. Control power, required for trimming, was a function of inlet ram forces and moments, thrust induced effects, and to a lesser extent, aerodynamic forces and moments.

Pitch control powers for the Tandem Fan and Tilt Nacelle airplanes vary primarily as functions of inlet ram moment and thrust induced effects. In fact, inlet ram moments play a key role in all axes. The inlet ram moment for the Tilt Nacelle airplane hovering in a headwind is a large positive value requiring a negative pitch control for trim. The positive ram pitch moment is due to the vertical displacement of the inlet when the nacelles are rotated 90 degrees plus an additional vertical arm component due to turning the capture streamtube from horizontal to vertical. Two of the Tandem Fan's inlets are located above the c.g. and all four are forward of the c.g. Tandem Fan pitch trim control is also negative in a headwind and almost all attributable to canceling out the ram moment. Pitch trim control power variation with wind direction, for these airplanes, reflects the variation in ram moments. Aircraft attitude in trim and the forward inlet location combine to produce a negative ram contribution at 90 degrees crosswind for the Tandem Fan airplane. This accounts for the large positive pitch control at this condition.

Thrust induced moments and ram moments are the primary moments that must be trimmed in the RALS and L+L/C airplanes also. The trim pitch control power for these airplanes shows much less variation than the subsonic airplanes. This occurs for two reasons: At a given thrust level the fan airplanes have higher inlet mass flows than the supersonic airplanes. Additionally, the

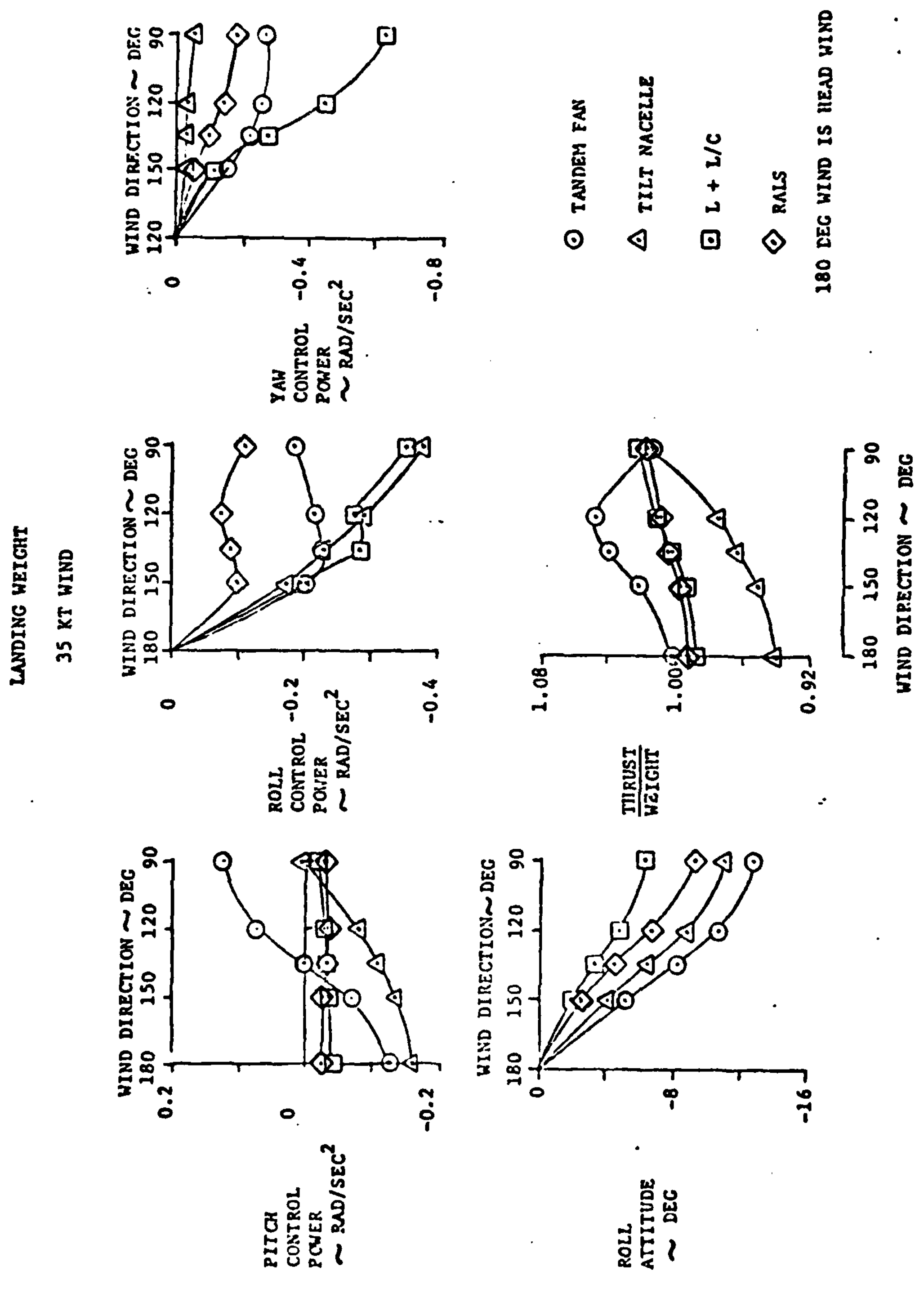


Figure 6. Hover in Wind Trim Summary

pitch inertia for the supersonic airplanes is nearly twice that of the subsonic airplanes. Ram pitching moment contribution is smallest in the RALS airplane. The RALS inlets are located forward of the c.g. but near the vertical centerline of the airplane.

Ram and aerodynamic moments are the primary contributors to roll and yaw trim control power requirements. The RALS airplane roll trim requirements are almost totally aerodynamic while trim required for the other three airplanes is a combination of aerodynamic and ram moments. In yaw, the tilt nacelle airplane trim control power level is small because the aerodynamic moments are low and the inlet ram contribution to yawing moment is also small. The fuselage aerodynamic contribution to yawing moment is largest for the L+L/C airplane and accounts for the difference in trim control power required at large crosswind angles.

Modal characteristics and key stability derivatives from the hover in 35 knot wind analysis are presented in figures 7 and 8. Note the similarity in modal characteristics (all modes are relatively low frequency) among the airplanes in deference to large differences in individual stability derivatives. This situation is typical of the unaugmented characteristics of VTOL aircraft at these low speeds. As airspeed increases, the aircraft modal characteristics become highly configuration specific (Appendix B).

The large differences in stability derivatives lead to observations regarding the relative gust sensitivities of the airplanes. The input forces and moments experienced by an airplane in a gust field are directly proportional to its unaugmented u, v, and w derivatives. Using this guideline and examining figure 8 reveals that with the exception of the X_u, Z_w, and Y_v derivatives, the airplanes are relatively insensitive to gusts. Virtually unrealizeable gust velocities on the order of 100 ft/sec are

V_{WIND} = 35 kts
$\gamma_0 = \theta_0 = 0^0$

$\psi_{WIND} = 180^0$ (HEADWIND)

	LONGITUDINAL			LATERAL-DIRECTIONAL		
	λ_1	λ_2	λ_3, λ_4	λ_1	λ_2	λ_3, λ_4
TANDEM FAN	-.502	-.201	.135 ± .375j	-.785	-.173	.223 ± .559j
TILT NACELLE	-.528	-.181	.039 ± .273j	-.701	-.030	.198 ± .508j
L+L/C	-.338	-.132	.115 ± .257j	-.663	-.047	.236 ± .512j
RALS	-.287	-.111	.090 ± .214j	-.614	-.042	.205 ± .462j

$\psi_{WIND} = 135^0$ (45^0 PORT CROSSWIND)

	λ_1	λ_2	λ_3, λ_4	λ_1	λ_2	λ_3, λ_4
TANDEM FAN	-.413	-.278	.192 ± .392j	-.703	-.103	.153 ± .478j
TILT NACELLE	-.423	-.165	.063 ± .254j	-.678	-.0372	.186 ± .493j
L+L/C	-.305	-.100	.111 ± .239j	-.687	-.0910	.260 ± .546j
RALS	-.242	-.903	.084 ± .188j	-.572	-.071	.186 ± .430j

$\psi_{WIND} = 90^0$ (90^0 PORT CROSSWIND)

	λ_1	λ_2	λ_3, λ_4	λ_1	λ_2	λ_3, λ_4
TANDEM FAN	-.298	-.193	.105 ± .245j	-.626	-.169	.181 ± .460j
TILT NACELLE	-.534	-.070	.224 ± .439j	-.675	-.0567	.214 ± .509j
L+L/C	-.259	-.038	.107 ± .211j	-.721	-.0926	.287 ± .582j
RALS	-.074	.085	-.046 ± .083j	-.606	-.079	.216 ± .468j

Figure 7. Hover in Wind Modal Characteristics Summary

ψ_{WIND} = 180° (HEADWIND)

AIRPLANE	X_u	Z_u	M_u	X_w	Z_w	M_w	Y_v	L_v	N_v
TANDEM FAN	-0.0357	-0.00716	0.00257	-0.00218	-0.227	0.0114	-0.0827	-0.00832	-0.00435
TILT NACELLE	-0.0822	-0.0810	0.00115	0.00676	-0.202	0.00006	-0.0649	-0.00657	0.00110
L + L/C	-0.0256	-0.0117	0.00082	0.00297	-0.149	0.00109	-0.0379	-0.00641	-0.00020
RALS	-0.0380	-0.00317	0.00048	0.00151	-0.118	0.00103	-0.0324	-0.00463	-0.00058

ψ_{WIND} = 135° (45° PORT CROSSWIND)

AIRPLANE	X_u	Z_u	M_u	X_w	Z_w	M_w	Y_v	L_v	N_v
TANDEM FAN	-0.0387	0.0157	0.00273	-0.0216	-0.177	0.0132	-0.159	-0.00512	-0.00426
TILT NACELLE	-0.0761	-0.0456	0.00084	-0.00707	-0.150	-0.00052	-0.129	-0.00594	0.00075
L + L/C	-0.0234	-0.00276	0.00066	-0.00211	-0.103	0.00065	-0.108	-0.00397	-0.0137
RALS	-0.0308	0.00220	0.0032	-0.00385	-0.0856	0.00111	-0.108	-0.00275	-0.00374

ψ_{WIND} = 90° (90° PORT CROSSWIND)

AIRPLANE	X_u	Z_u	M_u	X_w	Z_w	M_w	Y_v	L_v	N_v
TANDEM FAN	-0.0283	0.00070	0.00069	-0.00140	-0.0930	0.00765	-0.197	-0.00455	-0.00320
TILT NACELLE	-0.0449	-0.00043	0.00411	0.00834	-0.0701	0.00001	-0.164	-0.00663	0.00151
L + L/C	-0.0192	-0.00060	0.00045	-0.00023	-0.0388	0.00081	-0.150	-0.00389	-0.0200
RALS	-0.0138	-0.00044	-0.00002	-0.00044	-0.0442	0.00186	-0.152	-0.00360	-0.00466

Figure 8. Key Stability Derivatives Comparison – Hover in 35 Knot Wind

required to produce relatively small (0.1 rad/sec^2 or 0.1 ft/sec^2) accelerations of the aircraft. These results might be different if lateral and directional thrust induced effects were included. For example, the airplane of reference 5 had a much larger L_v than the airplanes in this study and was shown to be dominated by thrust induced effects. Further examination of the X_u, Z_w, and Y_v derivatives leads to the following statements regarding the relative low speed gust sensitivity of the four airplanes:

- The Tilt Nacelle airplane is two to three times more sensitive to horizontal gusts than the other airplanes. (X_u observation)

- The Tilt Nacelle and Tandem Fan airplanes are at most twice as sensitive to lateral and vertical gusts than the other airplanes. (Z_w and Y_v observation)

4.3.2 Forward Flight Characteristics

Current forward flight criteria have little impact on airplane design; but, it is possible that criteria changes could alter the significance of this regime. Consequently, forward flight characteristics were evaluated to demonstrate the implications of changes in current flying qualities criteria; i.e. design sensitivity to changes in criteria. The analysis presented here focuses on some of the ramifications of requiring bare airplane compliance with level 3 flying qualities; in particular, the requirement that any longitudinal divergence have a time to double amplitude equal to or greater than 5 seconds.

The attainment of acceptable (i.e. level 3) flying qualities is not always possible. In fact this may be a severe requirement. Possible solution depends on the airplane aerodynamics, inlet ram forces, and propulsion induced effects and attainment of a satisfactory blending of aerodynamic and propulsion controls. Selected analyses for two of the airplanes are presented below.

Figure 9 presents a pitch moment build up for the RALS airplane. Note that the thrust control requirement is small. Thrust induced moment is effectively cancelled by the aerodynamic moment. Inlet ram moment is small because of the inlet location with respect to the c.g. The minimal use of thrust control for trim is desirable because the full modulation range is still available for stabilization and maneuvering.

Modal characteristics are presented in figure 10. This is a classical root locus plot above the σ axis. Roots plotted below the σ axis actually fall on the real axis but are plotted against airspeed. This facilitates the tracking of roots along the real axis as airspeed varies. At low speeds the airplane is stable and the height mode is uncoupled. As speed increases an aperiodic divergence develops around 80 knots. By 120 knots, time to double amplitude is less than five seconds.

A primary contributor to the aperiodic divergence is M_u. Figure 11 presents a build up of the derivative M_u for the RALS airplane. Note that the derivative goes negative just prior to 80 knots and continues to larger negative values. Controls blending between aerodynamic and propulsion controls was previously mentioned. Figure 11 suggests this possibility. At the higher airspeeds M_u is dominated by the aerodynamic contribution; in particular the wing-body. One can envision shaping the canard load to generate a more positive contribution to M_u. This would cancel the adverse wing-body contribution. One problem that arises is whether the canard has sufficient deflection remaining, before stall occurs, to overcome the wing-body effect. Additionally, as the aerodynamic moment gets smaller the thrust control moment required grows larger. A particular canard scheduling might conceivably result in a switching of the thrust control and aero moment in figure 9. The ramification is obvious; aerodynamic and propulsion control may conflict. Aerodynamic control (the canard) is used up to shape M_u; at the same time increased propulsion control is required to offset the additional aerodynamic input. The particular amount of blending required is obviously a strong function of the airplane thrust induced and ram moments. The aerodynamic and propulsion conflicts encountered in attempting to tailor M_u lead to the conclusion that it was difficult to obtain satisfactory (level 3) modal characteristics for the RALS airplane throughout the forward flight regime.

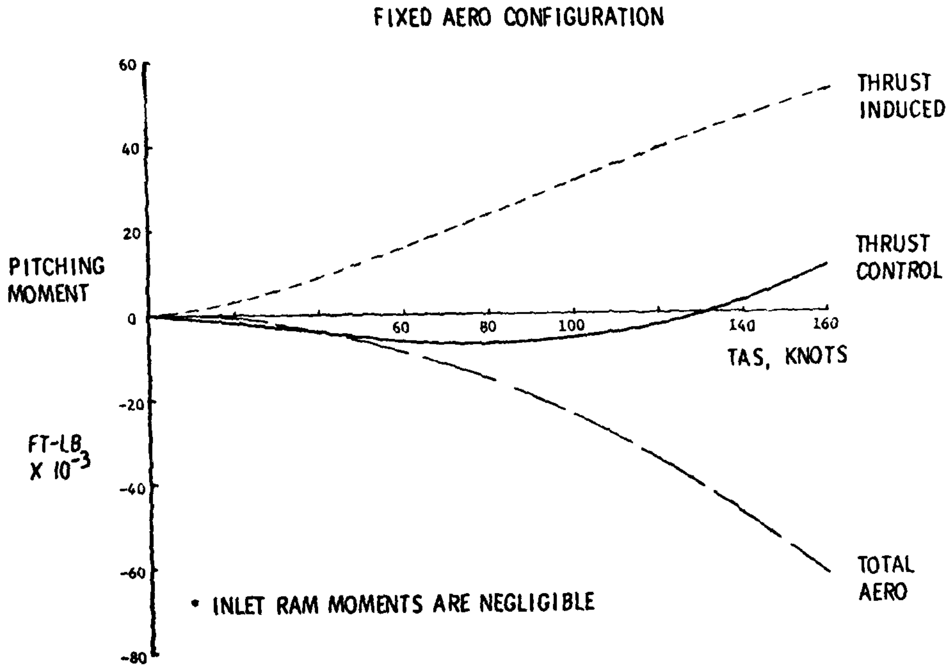


Figure 9. RALS Airplane Pitching Moment Contributions in Trimmed Level Flight

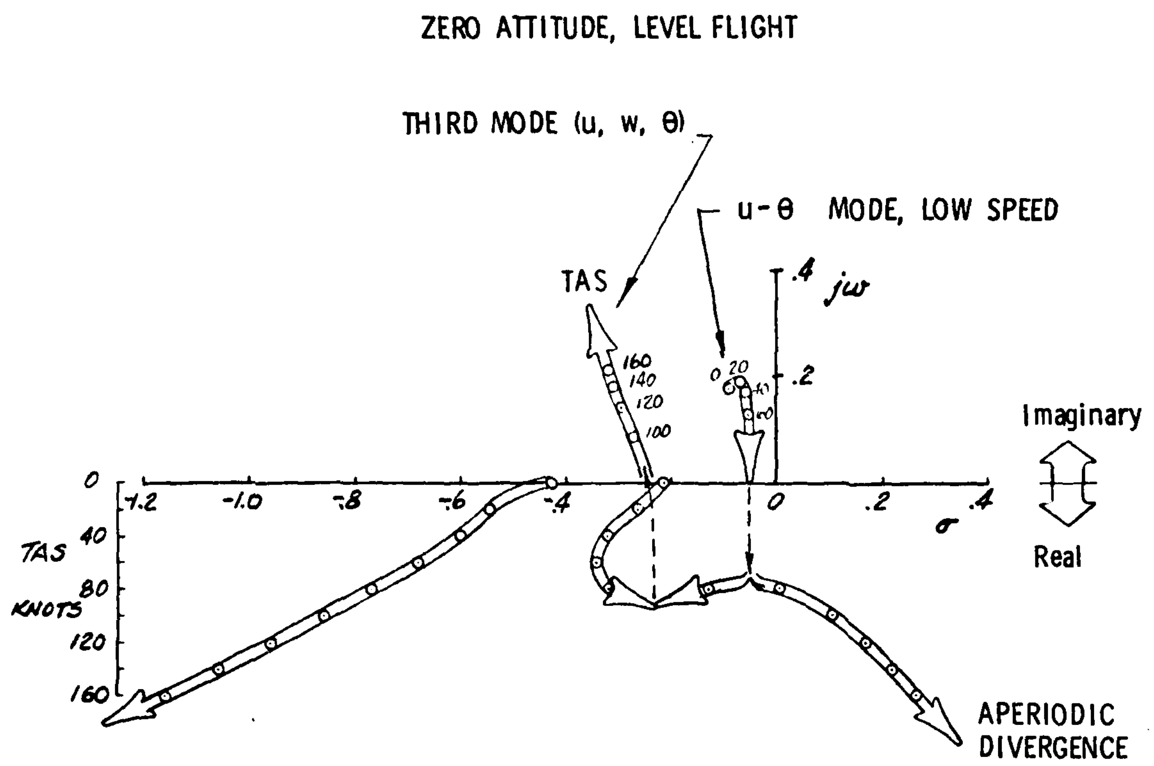


Figure 10. RALS Airplane Variation of Longidutinal Roots With Airspeed

The Tandem Fan airplane was more amenable to M_u and modal tailoring as indicated by figures 12 and 13. Figure 12 shows the effect of a series trim schedule on the real component of the unstable root at a speed of 80 knots. It is possible to attain a time to double amplitude of less than five

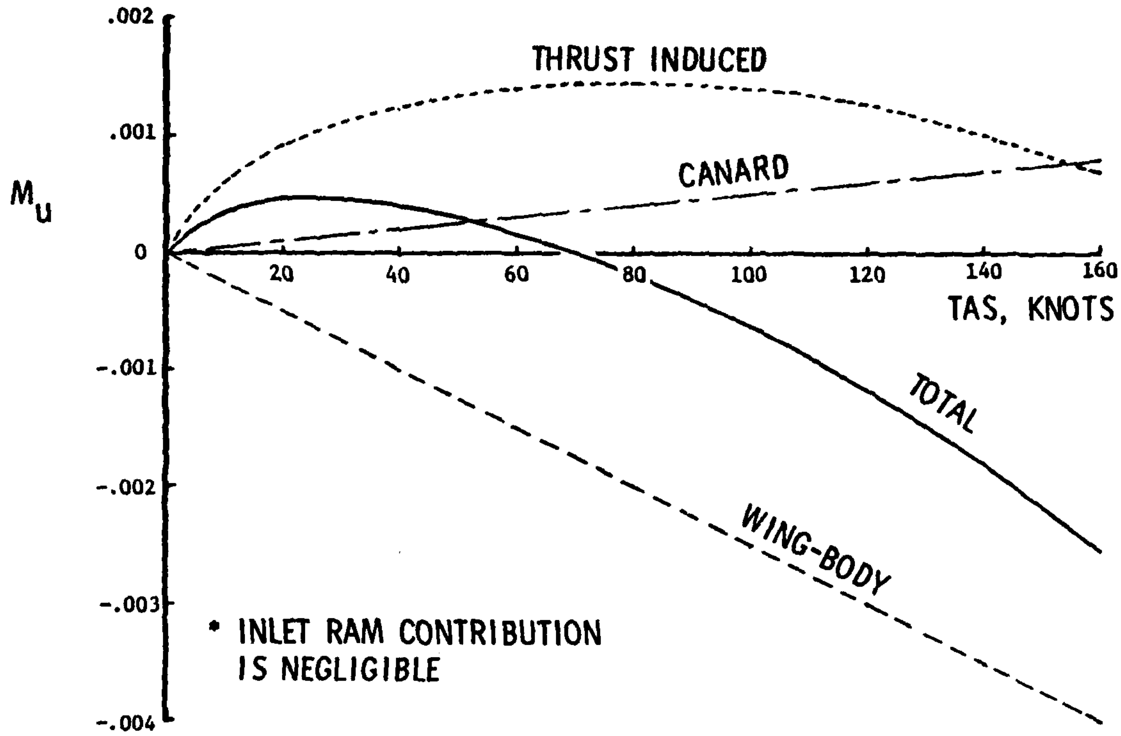


Figure 11. RALS Airplane Component Contributions to M_u Derivative

seconds. Also note that at 80 knots the thrust moment and horizontal tail moment almost cancel. Attainment of level 3 flying qualities occurs by moving the tail and thrust control in a favorable direction, i.e. both are unloaded. Trim requirements are thus minimized leaving a larger control margin for stabilization and maneuvering.

Horizontal tail series trim was also used to shape the modal characteristics (through M_u) at 140 knots, and these results are presented in figure 13. The airplane can be stabilized with a tail incidence of -2 degrees. However the tail must be loaded to obtain stabilization and a thrust moment developed to balance this tail load. At 80 knots the more desirable root location was obtained by unloading the propulsion system but at 140 knots the opposite was true.

A combination of series trim scheduling (vs. airspeed, thrust incidence angle, etc.) and controls blending may produce acceptable flying qualities; in this case acceptable was taken to be level 3 for the bare airframe. However, one must consider whether forward loop gearing and shaping is worth the effort. With a fly-by-wire flight control system on board it may be more practical to stabilize the airplane via feedback control.

Summarizing; M_u is a key derivative in establishing longitudinal modal characteristics in the forward flight regime. M_u is sensitive to the blending of aerodynamic and propulsion control for trim, and to configuration specific ram and thrust induced effects. It should be pointed out that the degree of modal variation attainable with M_u is a strong function of the value of M_w. Specific values of M_w for which M_u is most effective in altering modal characteristics varies with airplane configuration. In general, positive increases in M_w reduce the effectiveness of M_u and increasing negative values of M_w enhance the effectiveness. In regards to

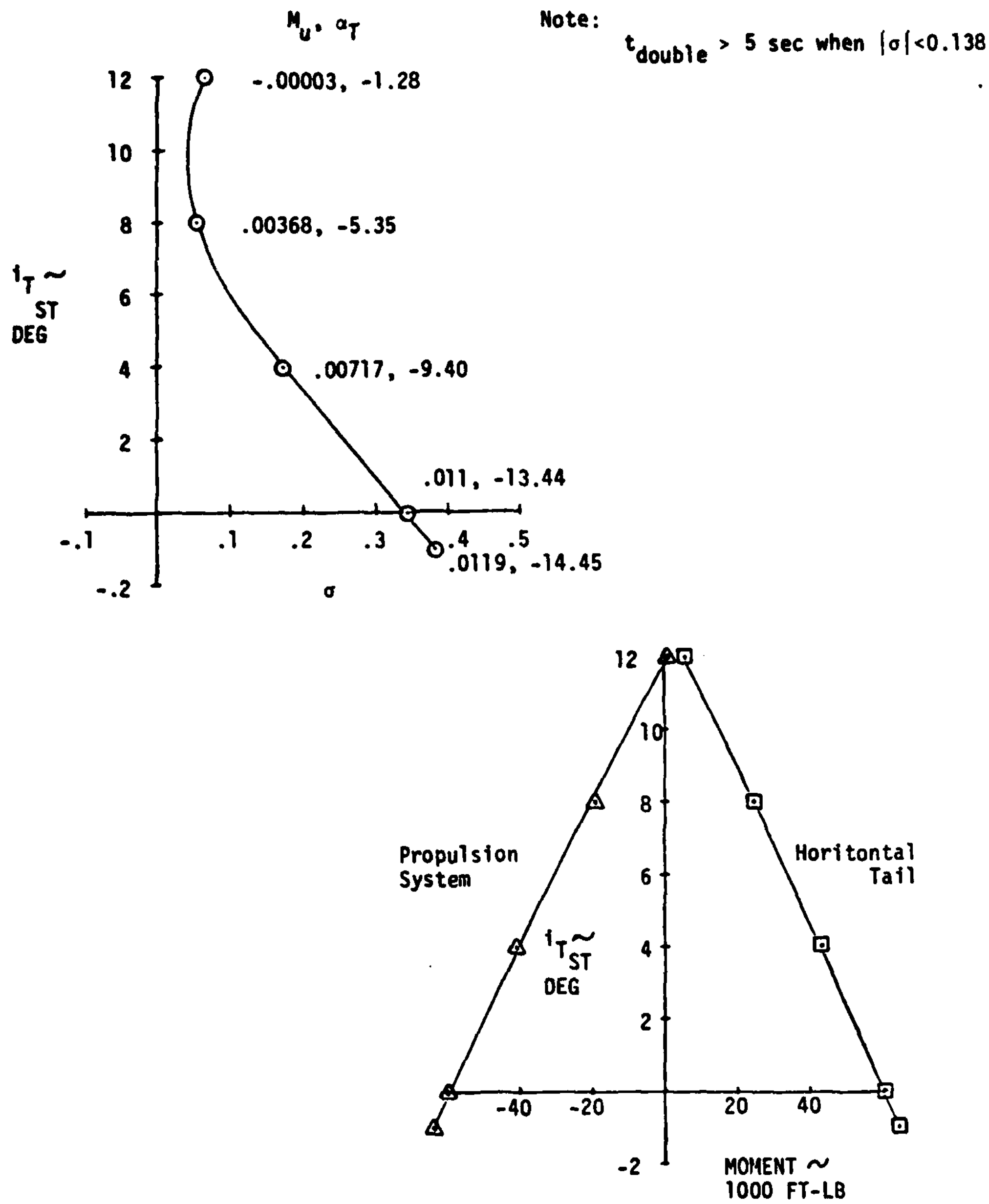


Figure 12. Effect of Horizontal Tail Series Trim on Tandem Fan M_u Derivative and Modal Characteristics at 80 Knots

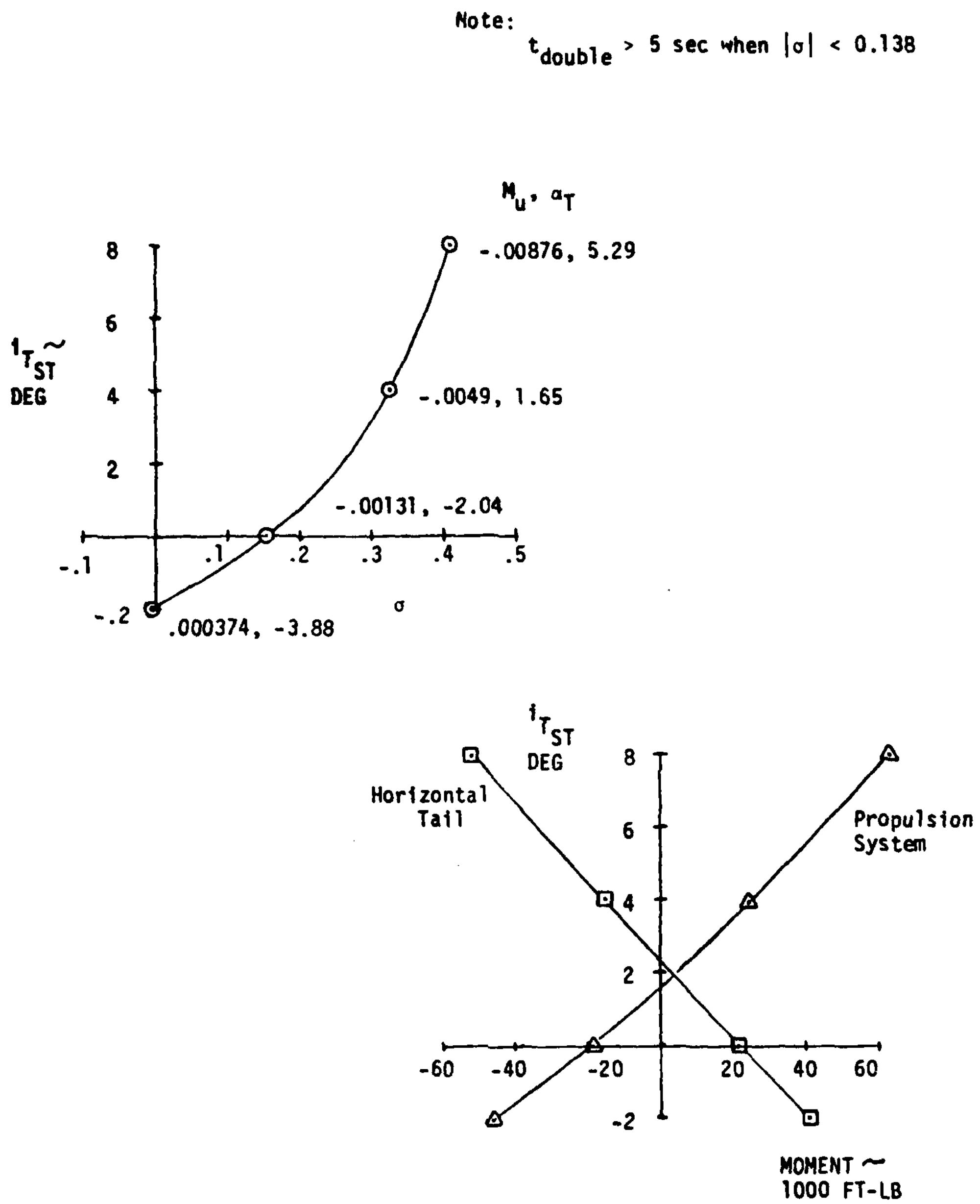


Figure 13. Effect of Horizontal Tail Series Trim on Tandem Fan M_u Derivative and Modal Characteristics at 140 Knots

the hypothesized criteria change, bare airframe compliance to level 3 may be a severe requirement. The analysis involves looking at the complexity of controls blending and the resulting possibility of conflicting requirements. For example, at 140 knots the Tandem Fan required a significant thrust control moment to offset the moment generated by the horizontal tail (which was positioned to obtain desirable roots). At this speed it is desirable that thrust control moment start to diminish. Ideally, by V_{con} the airplane should be flying on aerodynamic control. It was also pointed out that a potentially complex gearing and scheduling may be required. It may be simpler and less expensive to let the flight control system handle stabilization in this case.

4.3.3 Conventional Flight Characteristics

Analysis of conventional flight characteristics was limited to the low speed cruise regime. Variation of horizontal and vertical tail sizes provided the flying qualities interface with design and performance parameters. Tail size variation normally has only a small effect on mission performance as these results show. It should not be inferred that tails are normally sized for this speed regime. In fact, Mach and flexibility effects are significant contributors to tail sizing. These effects were not considered in this study.

Low speed longitudinal modal characteristics for the four airplanes are presented in Table 6 for two horizontal tail (canard) sizes. These data were obtained by varying tail (canard) area ten percent at a speed of 1.4 V_{STALL}. Unaugmented baseline aircraft characteristics are compared with MIL-F-8785B requirements in Figure 14. All baseline aircraft satisfy level 3.

Lateral-directional modal characteristics of the airplanes are presented in Table 7 for two vertical tail areas. These data were obtained at a speed of 1.4 V_{STALL} by varying vertical tail area ten percent as in the longitudinal example. Variation of tail area produces the expected results on lateral-directional characteristics. Each of the unaugmented airplanes satisfy level 3 MIL-F-8785B requirements.

TABLE 6
EFFECT OF TAIL SIZE ON LONGITUDINAL CHARACTERISTICS

Clean Configuration, $V/V_S = 1.4$, Fixed c.g., Combat Weight

AIRPLANE	$\frac{S_{HT}}{(S_{HT})_O}$	TAS ~ KNOTS	SM ~ $\%\bar{c}$	$\omega_{n_{SP}}$	ζ_{SP}	n_z/α
TANDEM FAN	1.0	186	5.39	1.51	.665	8.51
	1.1	186	7.82	1.75	.606	8.51
TILT NACELLE	1.0	192	7.55	1.95	.875	8.10
	1.1	192	15.55	2.53	.730	8.40
L + L/C	1.0	206	4.97	1.07	.496	6.46
	1.1	206	6.76	1.23	.451	6.54
RALS	1.0	197	3.16	.939	.447	5.90
	0.9	197	4.51	1.08	.373	5.81

TABLE 7
EFFECT OF VERTICAL TAIL SIZE ON LAT-DIR CHARACTERISTICS

Clean Configuration, $V/V_S = 1.4$, Fixed c.g., Combat Weight

AIRPLANE	$\frac{S_{VT}}{(S_{VT})_O}$	TAS ~ KNOTS	ω_{n_D}	ζ_D	SPIRAL ROOT	ROLL ROOT
TANDEM FAN	1.0	186	1.84	.064	.0099	-1.634
	1.1		1.93	.072	.01150	-1.626
TILT NACELLE	1.0	192	1.56	.0588	.0267	-1.172
	1.1		1.65	.0619	.0269	-1.174
L + L/C	1.0	206	1.57	.0433	-.0138	-1.013
	1.1		1.68	.0582	-.0090	-1.002
RALS	1.0	197	1.56	.124	-.0257	- .758
	1.1		1.68	.132	-.023	- .730

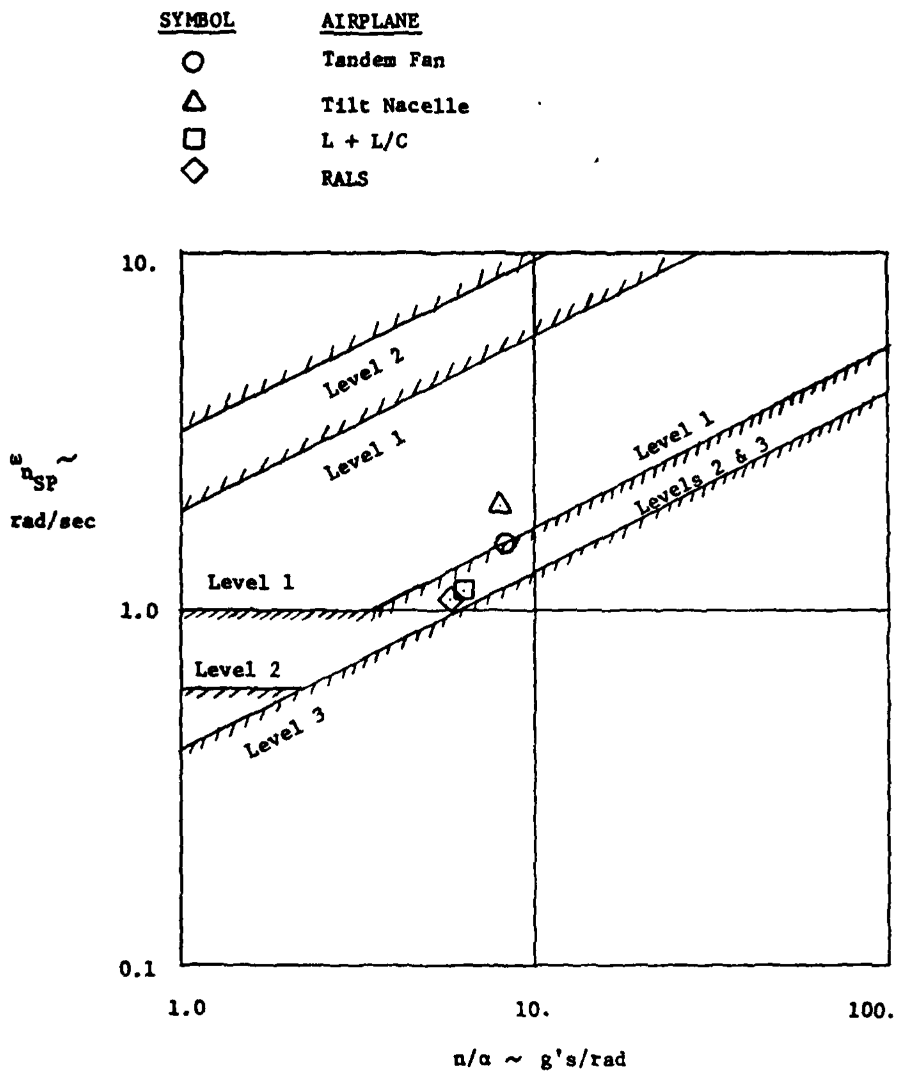


Figure 14. Short-Period Frequency Characteristics for the Four V/STOL Airplanes

5.0 SENSITIVITY TO FLYING QUALITIES

5.1 Basic Sensitivity Relations

Basic design and mission sensitivities were evaluated for each of the four airplanes. The distinction between the two types of sensitivities is defined as follows:

- Design sensitivity reflects the difference in TOGW and size parameters due to change in requirements or design constraint parameters. Any design selection resulting from this sensitivity relation will satisfy the given mission requirements. This sensitivity was evaluated by the same parametric design procedure used for baseline airplane selection (described in Appendix A).

- Mission sensitivity reflects the variation in mission performance parameters due to modifications to a point design after its selection. In this case the airplane is frozen, except for the specific modifications, and the resulting mission capability is a fallout.

Table 8 indicates the basic sensitivity parameters evaluated for each airplane.

TABLE 8

BASIC SENSITIVITY EVALUATION MATRIX

INDEPENDENT PARAMETER	DEPENDENT PARAMETERS	
	TOGW	MISSION PERFORMANCE
TAKEOFF T/W	X	X
PROPULSION CONTROL POWER	X	X
HORIZONTAL TAIL SIZE		X
VERTICAL TAIL SIZE		X
DEAD WEIGHT		X

Mission performance sensitivities for takeoff T/W, propulsion control power, and dead weight were evaluated with appropriate changes in fuel available. The fuel system weight was scaled to match the fuel available, assuming adequate volume was available in the airplane for the case when fuel is added. Structural weight was not increased for an overload due to added fuel.

The effects of changes in tail size were evaluated by changing the fuel load along with an appropriate structural weight change and a drag adjustment.

Linear sensitivity relations for small perturbations from the design point are summarized in Table 9 for each airplane. Comparison of these relations indicates the design sensitivities for TOGW and propulsion control provisions are generally configuration specific with some significant variation between different propulsion system concepts. However mission sensitivities are generally less variant between the airplanes within a mission type.

The design sensitivities for the lift plus lift/cruise airplane are significantly lower than the other airplanes for several reasons. As a result of the nominal 60%/40% thrust split between the lift and lift/cruise engines in the vertical mode, the lift/cruise engines were sized by mission requirements and were larger than required for the vertical mode. Thus the design sensitivity relations primarily reflect the effect of changing only the lift engines for T/W and control provisions rather than resizing the entire propulsion system as would be required in the other lift/cruise concepts. These effects are discussed in Appendix A, Section A.3 relative to the selection of the baseline airplane.

Both design and mission sensitivity relations as a function of takeoff T/W and propulsion control provisions were considered especially important in this study. These sensitivities were evaluated over large parametric ranges and are presented in the form of carpet plots in following sections. These carpet plots show the nonlinear effects of large parameter changes and generally provide better insight into potential design tradeoffs.

5.2 Design Sensitivity to Flying Qualities

Design sensitivities to flying qualities were evaluated in two ways. First, the basic linear sensitivity relations from 5.1 were converted into control power sensitivities which are convenient norms for comparing the four airplanes at their baseline design points. However, large variations in attitude control provisions and T/W variations can result in significant nonlinearities which were apparent from the parametric carpet plots developed for each airplane. The second method used to evaluate these large variations was to compare the resulting TOGW for alternate point designs selected to satisfy different control power criteria. Results of this second method provide a better indication of the design sensitivity to total control provisions and highlight the importance of satisfactory flying qualities design criteria.

5.2.1 Propulsion Control Power Sensitivities

Control power sensitivity relations for propulsion control in vertical mode operation are summarized in Table 10 for the four airplanes. These relations combine the sensitivities in Table 9 with the specific control effectiveness for each airplane. Thus they reflect differences in geometry and moments of inertia, as well as differences in the sensitivity to control provisions of each propulsion system.

The comparison shows the vertical landing condition is usually the more

TABLE 9

PERFORMANCE SENSITIVITY SUMMARY

SENSITIVITY TO \ A/C	TANDEM FAN	TILT NACELLE	LIFT + LIFT/CRUISE	RALS
VTO T/W -				
TOGW	340 lb/% T/W	500 lb/% T/W	75 lb/% T/W	360 lb/% T/W
ASW TOS	8 min/% T/W	8 min/% T/W	—	—
DLI R/A	—	—	3nm/% T/W	9nm/% T/W
Control Parameter -				
TOGW	270 lb/% $\Delta F_G/F_G$	400 lb/%$(\Delta F_G/F_G)^1$ 800 lb/%$(\Delta F_G/F_G)^2$	53 lb/lb/sec Bleed Flow	500 lb/lb/sec Bleed Flow
ASW TOS	7 min/% $\Delta F_G/F_G$	6.5 min/%$(\Delta F_G/F_G)^1$ 13.0 min/% $(\Delta F_G/F_G)^2$	—	—
DLI R/A	—		7nm/lb/sec Bleed Flow	6nm/lb/sec Bleed Flow
Horizontal/Rear Wing/ Canard Size -				
ASW TOS	0.075 min/Ft^2	0.08 min/Ft^2	—	—
DLI R/A	—	—	0.28 nm/Ft^2	0.32 nm/Ft^2
Vertical Tail Size -				
ASW TOS	0.14 min/Ft^2	0.135 min/Ft^2	—	—
DLI R/A	—	—	0.23 nm/Ft^2	0.26 nm/Ft^2
Empty Weight Variation -				
ASW TOS	2.8 min/100 lb	2.6 min/100 lb	—	—
DLI R/A	—	—	2.6 nm/100 lb	3.1 nm/100 lb

1 Fan control
2 Bleed flow

TABLE 10
PROPULSION CONTROL POWER SENSITIVITIES

AIRPLANE	TOGW / T/W (lb/%)	PITCH CONTROL SOURCE	TOGW / PCP (lb/%)	ROLL CONTROL SOURCE	TOGW / RCP (lb/%)
TANDEM FAN	340	FAN THRUST	75 (VL) 68 (VTO)	FAN THRUST	59 (VL) 55 (VTO)
TILT NACELLE	500	BLEED	160 (VL) 120 (VTO)	FAN THRUST	124 (VL) 100 (VTO)
L + L/C	75	BLEED (LIFT ENG)	54 (VL) 43 (VTO)	BLEED (LIFT ENG)	12 (VL) 16 (VTO)
RALS	360	RALS/ADEN NOZZLE THRUSTS	126 (VL) 95 (VTO)	BLEED	30 (VL) 36 (VTO)

NOTES: VL - Vertical landing weight; VTO - Vertical takeoff weight. Control power relations are based on unity control power, i.e. 100% CP = 1 rad/sec^2.

sensitive loading for defining attitude control provisions. This occurs because the propulsion control available is proportional to the nominal thrust required, which is proportional to weight; but moments of inertia are not proportional to weight, and the ratio of inertia to weight is usually higher at landing weight. An exception is noted for roll control power sensitivities for the two supersonic airplanes which carry fuel in their wings, resulting in a different inertia variation with operating weight. However, the roll moments of inertia for the supersonic airplanes are always much lower than the two subsonic fan configurations, which results in the much lower control power sensitivity relations for these airplanes. Other differences in the sensitivity comparison can be explained by a combination of inertia, geometry, and the particular propulsion system sensitivity.

5.2.2 Total Control Power Sensitivities

A part of the parametric design process was to develop the parametric relations for TOGW as a function of T/W and attitude control provisions. These nonlinear parametric relations were developed for each airplane and will be introduced subsequently in the form of carpet plots. It was not practical to convert these relations into the desired form of T/W and control power parameters, so another approach was necessary to illustrate the sensitivity of each design to total control provisions. The chosen approach was to select two levels of control power and compare the difference in TOGW between airplanes satisfying the two levels. It was also desired that the levels selected would represent a reasonable range between minimum and maximum control power provisions indicated by currently available criteria. This approach led to an arbitrary selection of control power levels based on two methods of computing MIL-F-83300 requirements. Recent flight simulation test results from reference 6 fall within the control power range selected and provide some additional information pertinent to the continuing development of reasonable V/STOL flying qualities criteria.

The key requirements in MIL-F-83300 for flight control power are defined in paragraphs 3.2.5, 3.2.5.1, and 3.2.3.1 for the hover and low speed flight regime. For moderate to high disk loading airplanes such as those in this study, inherent vertical damping is relatively small and meeting the vertical acceleration requirement of 3.2.5.1 requires a T/W of approximately 1.10. Paragraph 3.2.5 requires that the vertical acceleration requirement be met while the simultaneous attitude requirements of 3.2.3.1 are maintained in reserve at the most critical wind direction for winds up to 35 knots.

The 3.2.3.1 MIL-F-83300 requirements are stated in terms of simultaneous control power reserves. The usual method of evaluating the minimum attitude

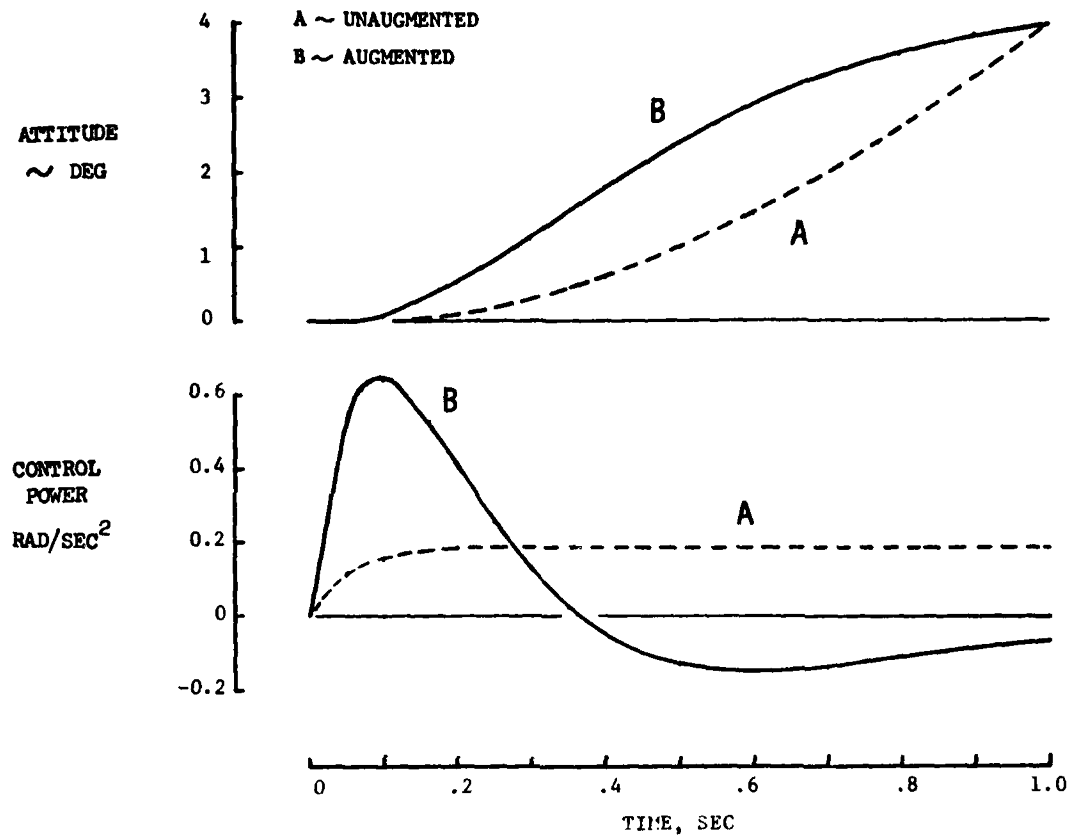


Figure 15. Comparison of Augmented and Unaugmented Attitude Response

control power for reserve is to neglect the flight control augmentation system which results in the minimum control power required to achieve the specified response in each axis. This method corresponds to saturated operation of the flight control system in each axis and was used here to establish minimum control power levels. Higher control power reserves would be required if a high bandwidth control augmentation system were used and saturated operation were not allowed. A comparison in Figure 15 shows 3.5 times more control power would be required with a 3 rad/sec bandwidth attitude stabilization system. This was not considered a valid interpretation of MIL-F-83300, but the method was chosen as an expedient means to set the upper level of control power for purposes of the sensitivity analysis.

Review of the flight simulation test results from the V/STOL flight control/flying qualities study of reference 6 provided some additional insight to flight control power requirements. Table 6-5, page 94 in reference 6 summarizes control power usage statistics (rms values) for the final 100 feet of approach and landing. Average control power statistics are summarized in Figure 16 for all approaches tested at 35 knots wind-over-deck and aligned with the approach path (i.e. $\psi_{wod} = -30^0$; refer to Figure 17 for approach geometry). The computed fan thrust modulation required to produce the control power statistics is also shown in Figure 16. The root sum of squares of the separate axis thrust modulations compares closely with the total measured one sigma thrust modulation of the aft fans. This result indicates the individual axis control demands for thrust from the common effectors are orthogonal and not simultaneous. (Note the consistency with pilot modeling theory where the pilot time-shares between the separate control axes.) This is significant in defining the total control power requirements for any airplane that uses a common control effector or power source (e.g. bleed air) for more than one axis.

The control power statistics in Figure 16 also provided an indication of attitude control power required above trim. The statistical properties of the simulation test data have not been analyzed, so there was some uncertainty in estimating a maximum control power level from the available rms statistics. As a result it was assumed that a range from 2.0 to 2.5 times the rms control power levels would provide at least a reasonable indication of total requirements for attitude regulation. The resulting attitude control power levels predicted in this manner are summarized in Figure 18 along with the assumed minimum and extreme levels for satisfying MIL-F-83300 attitude control reserves. This comparison shows the estimates from the test data fall between the minimum and extreme levels based on attitude reserves. It is interesting to note that an airplane could satisfy the minimum attitude reserve requirements and not have enough control power to satisfy the levels indicated from the flight simulation results.

Figures 19, 20, 21, and 22 present TOGW variation with control power requirements for the study airplanes. Each plot highlights three points: BASELINE, A, and B. Points labeled BASELINE correspond to the baseline point

TEST CONDITIONS:
- BASELINE ATTITUDE FCS
- WOD = 35 KNOTS, ψ_{WOD} = -30^{o}

AXIS	$1\ \sigma$ CP USED	EQUIVALENT Δ T/T,%
PITCH	.127 RAD/SEC^2	2.08
ROLL	.294 RAD/SEC^2	6.26
YAW	.056 RAD/SEC^2	-
HEAVE	.0308 g	3.08
	ADDITIVE TOTAL	11.42
	ROOT SUM OF SQUARES	7.28
	MEASURED TOTAL	7.33 (AVERAGE AFT FANS)

Figure 16. Control Power Statistics Summary from Recent Simulation

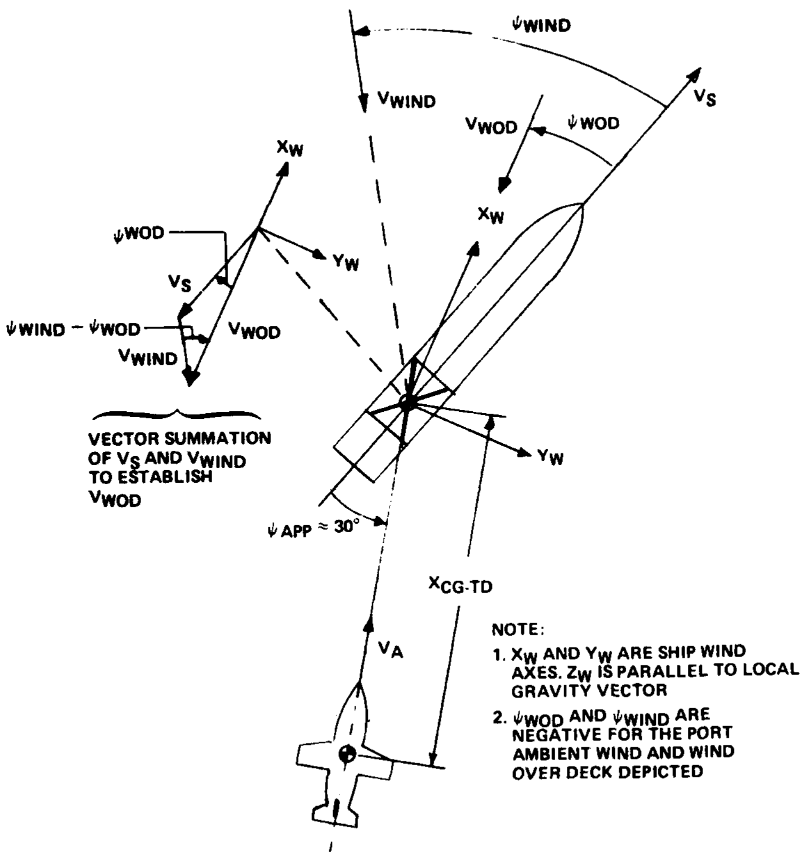
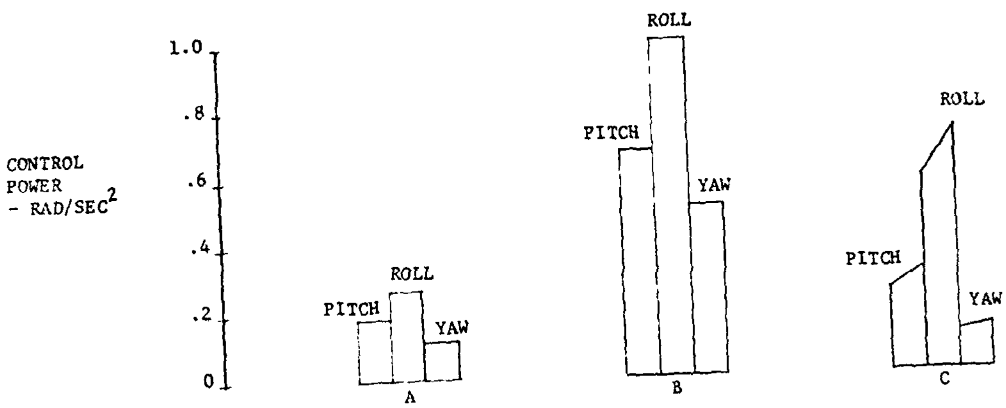


Figure 17. Landing Approach Geometry



A - NO AUGMENTATION OR SATURATED SYSTEM

B - 3 RAD/SEC ATTITUDE AUGMENTATION, NO SATURATION

C - RECENT SIMULATION RESULTS @ 35 KNOTS W.O.D., $\psi_{WOD} = -30°$

Note: For case C the lower edge of the bar-top represents a 2σ control power level. The higher edge is 2.5σ.

Figure 18. Attitude Control Power Requirements in Hover/Low Speed

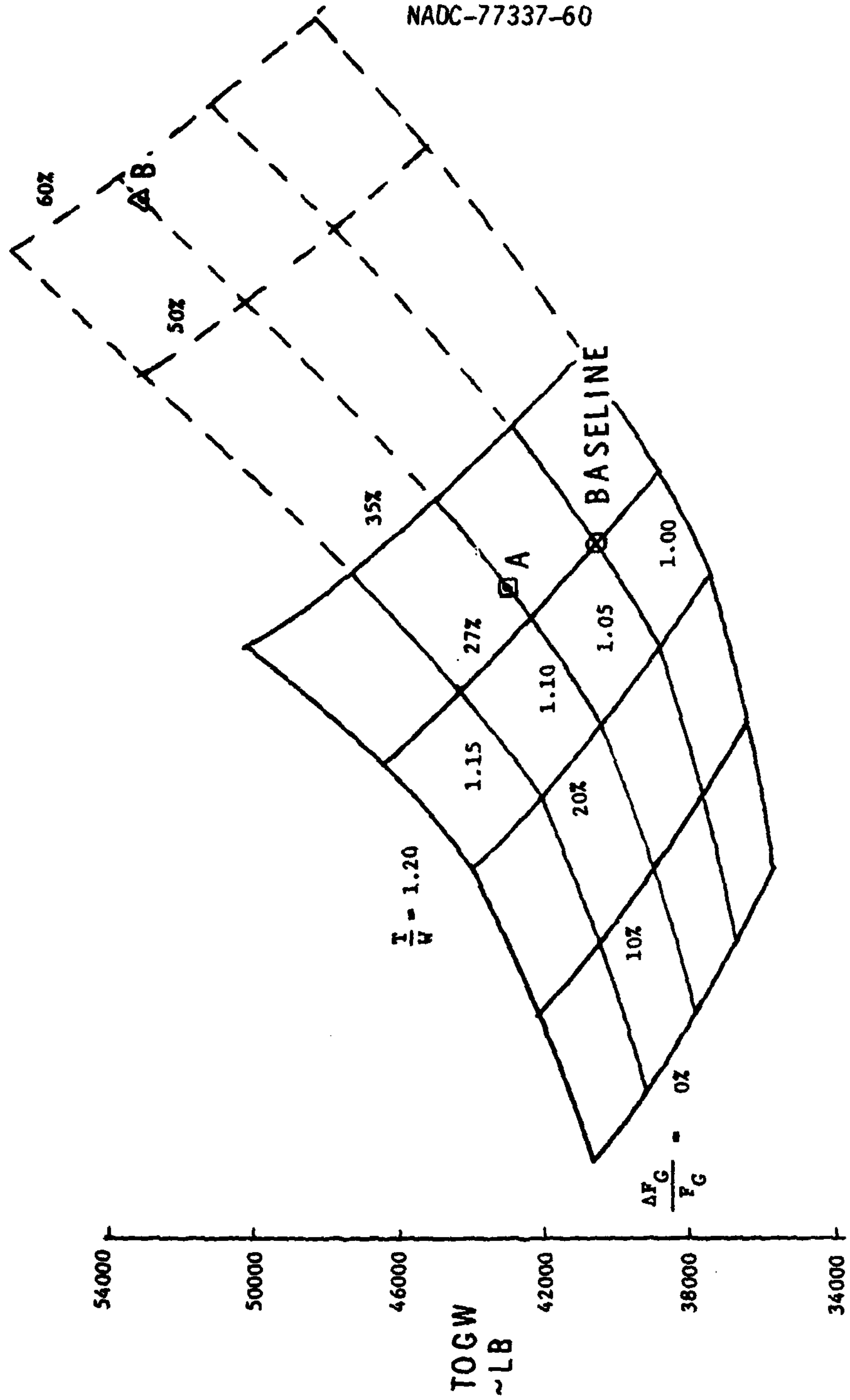


Figure 19. Tandem Fan Airplane TOGW Variation With T/W and Fan Modulation

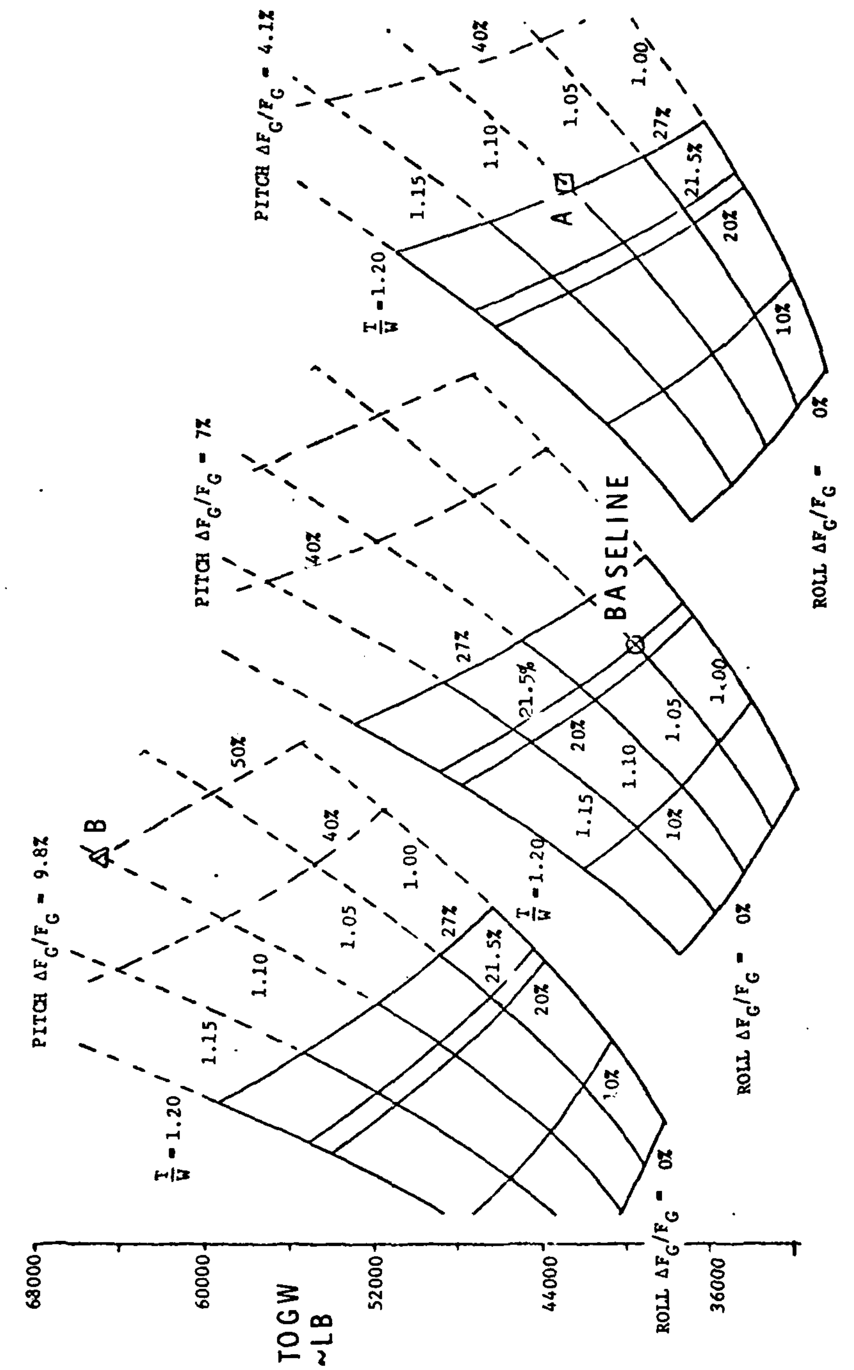


Figure 20. Tilt Nacelle Airplane TOGW Variation With T/W and Roll and Pitch Modulation

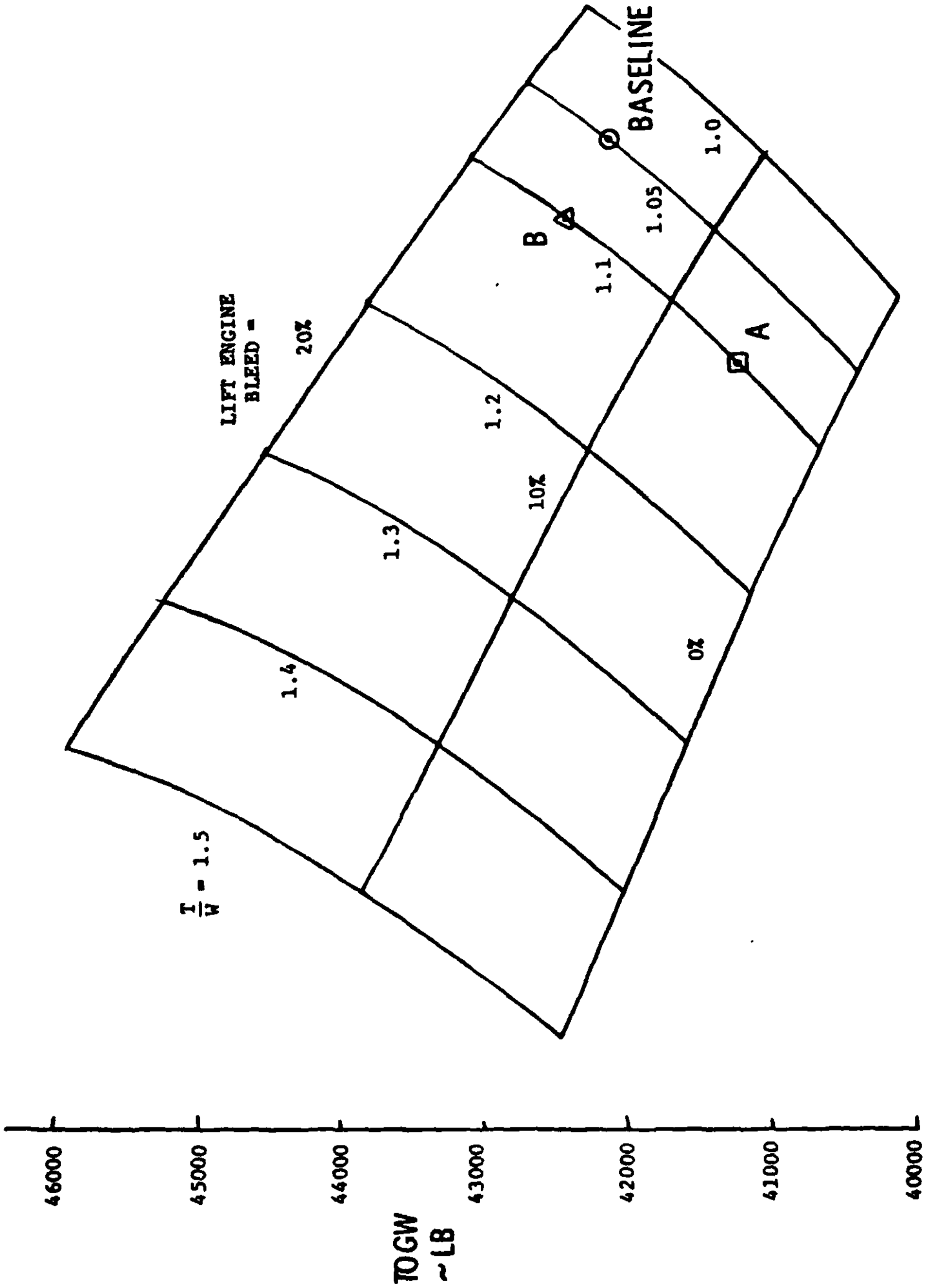


Figure 21. Lift Plus Lift/Cruise Airplane TOGW Variation With T/W and Lift Engine Bleed

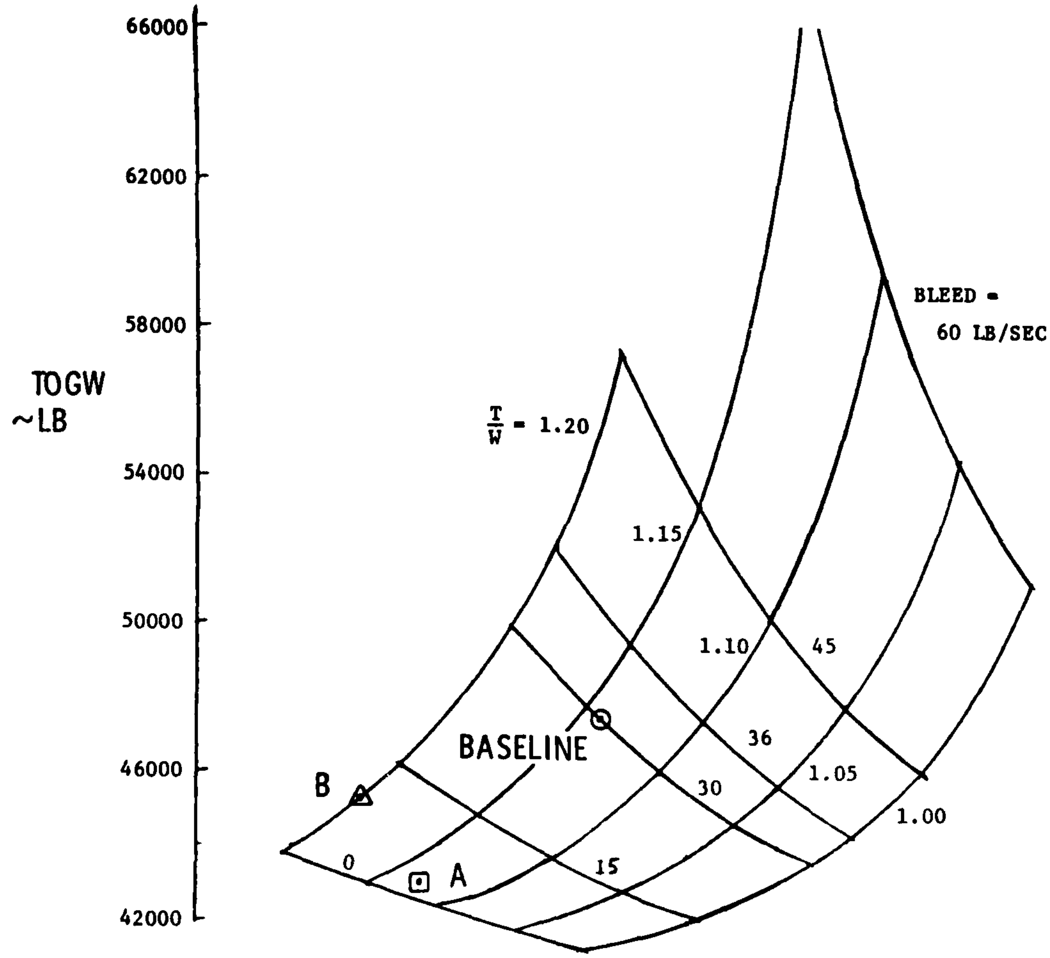


Figure 22. RALS Airplane TOGW Variation With T/W and Bleed Air Flow

design whose development is discussed in Appendix A. Airplanes designed to meet the minimum level control power requirements are labeled A, and airplanes which meet the higher level of requirements are labeled B. These airplanes, labeled A and B, have attitude control power levels corresponding to those similarly labeled in Figure 18. Note that three separate carpets are required for the Tilt Nacelle airplane. Each carpet represents a different bleed level requirement for pitch control.

The Tandem Fan and Tilt Nacelle carpets point out the severe design penalties which are possible and highlight the necessity for selecting new criteria wisely and not arbitrarily. Key factors in the large design variations obtained for the subsonic airplanes were: (1) the simultaneous control requirements for airplanes employing common effectors; and (2) the attitude requirements defined assuming an unsaturated augmentation system. Fans in the subsonic airplanes serve as common effectors; roll, pitch, and height control in the tandem fan, and roll and height control in the tilt nacelle. The upper level control power requirement (B) is obviously unreasonable for these airplanes. Current state-of-the-art in VIGV modulation capabilities limit thrust control to about $\pm 35\%$. The supersonic airplanes show a much lower sensitivity to control power requirements because control in each axis is obtained more or less independently of the other axes. Another reason is that most of the penalty is paid in the initial sizing. Consider the L + L/C airplane. The lift engines provide bleed for roll and pitch control. Once the engines are installed for VTOL lift, the main penalty has been paid. They are designed for high thrust to weight and are affected only slightly to provide bleed. At most, only one part of the propulsion system absorbs most of the growth if increased bleed were required. To get more thrust out of the subsonic airplane's fans requires fan size to grow and this impacts the size of the entire propulsion system.

5.3 Mission Sensitivity to Flying Qualities

Mission performance parameters selected for the sensitivity analysis were time on station (TOS) for the subsonic airplanes and radius of action (R/A) for the supersonic airplanes. Comparison of mission sensitivities between types (subsonic and supersonic) was therefore not possible. Mission performance sensitivities varied only slightly between airplanes of similar type as shown in Table 9. The exception was radius of action with respect to T/W for the supersonic airplanes. The L+L/C airplane differs from the RALS for the same reasons previously discussed concerning differences in TOGW sensitivity to T/W.

Tables 11 and 12 present mission sensitivity to short period frequency and Dutch roll frequency respectively. These results were obtained by combining the basic airplane sensitivities of Table 9 with the tail size effects on longitudinal and lateral-directional characteristics in Tables 6 and 7.

5.3.1 Mission Sensitivity to Short Period Frequency Criteria

The magnitude of the mission sensitivity does not vary significantly among airplane types. The radius of action sensitivity to short period frequency for the RALS airplane has a different sign from the L+L/C sensitivity. This change in sign is due to the RALS having a canard and the L+L/C a conventional horizontal tail. Increasing canard area is destabilizing (area forward of c.g.) while increasing horizontal tail area is stabilizing.

5.3.2 Mission Sensitivity to Dutch Roll Frequency Criteria

Mission sensitivity to Dutch roll frequency are also similar among types. These results are probably less meaningful than those in section 5.3.1 since

Dutch roll frequency generally does not size vertical tails, especially at the conditions examined here.

5.4 Sensitivity Summary

Design sensitivities to T/W and propulsion control provisions are generally configuration specific with some significant variation between

TABLE 11

MISSION SENSITIVITY TO SHORT PERIOD FREQUENCY

AIRPLANE	$(S_{HT})_0$	$(\omega_{n_{SP}})_0$	$\frac{\Delta TOS}{\Delta S_{HT}}$	$\frac{\Delta R/A}{\Delta S_{HT}}$	$\frac{\Delta \omega_{n_{SP}}}{\Delta S_{HT}}$	$\frac{\Delta TOS}{\Delta \omega_{n_{SP}}}$	$\frac{\Delta R/A}{\Delta \omega_{n_{SP}}}$
	ft^2	rad/sec	min/ft^2	nm/ft^2	rad/sec/ft^2	min/rad/sec	nm/rad/sec
TANDEM FAN	126	1.51	-0.075	-	0.0190	-3.95	-
TILT NACELLE	219	1.95	-0.08	-	0.0265	-3.02	-
L + L/C	95.6	1.07	-	-0.28	0.0167	-	-16.8
RALS	85.0	.94	-	-0.32	-0.0183	-	+17.5

TABLE 12

MISSION SENSITIVITY TO DUTCH ROLL FREQUENCY

AIRPLANE	$(S_{VT})_o$ ft^2	$(\omega_{n_D})_0$ rad/sec[2]	$\frac{\Delta TOS}{\Delta S_{VT}}$ min/ft[2]	$\frac{\Delta R/A}{\Delta S_{VT}}$ nm/ft[2]	$\frac{\Delta \omega_{n_D}}{\Delta S_{VT}}$ rad/sec/ft[2]	$\frac{\Delta TOS}{\Delta \omega_{n_D}}$ min/rad/sec	$\frac{\Delta R/A}{\Delta \omega_{n_D}}$ nm/rad/sec
TANDEM FAN	80	1.84	-0.14	-	0.01175	-11.9	-
TILT NACELLE	90	1.57	-0.135	-	0.00989	-13.6	-
L + L/C	95.1	1.57	-	0.23	0.01157	-	-19.5
RALS	85	1.56	-	0.26	0.01412	-	-18.4

different propulsion system concepts. Mission sensitivities are generally less variant between the airplanes within a mission type.

Results also show sensitivity to requirements or interpretation of requirements has a significant impact on airplane size, especially for airplanes employing common effectors for control. Recent simulation results indicated that a straight summation of control power requirements for simultaneous control may not be correct. More work along the lines of the V/STOL flight control/flying qualities study is required to ensure realistic VTOL control power criteria are developed.

6.0 RESULTS AND CONCLUSIONS

Evaluation of airplane design sensitivity to flying qualities criteria was a simple procedure after specific sensitivity factors were defined for:

- TOGW sensitivity to T/W and propulsion control power provisions
- Mission sensitivity to design variation

These design and performance sensitivities were the starting point for the flying qualities sensitivity study.

Thrust margin and control power provisions were the most important design considerations. As expected, design sensitivities were configuration specific since takeoff gross weight sensitivity to thrust margin and propulsion control provisions vary for different types of propulsion systems. TOGW for the two subsonic aircraft differed by only 6 percent, but the sensitivity to T/W and roll control provisions for the Tilt Nacelle were 1.5 times those for the Tandem Fan. Exponential increase of propulsion system weight with fan diameter accounted for most of this sensitivity difference, because the fans in the two-fan Tilt Nacelle aircraft were significantly larger than the fans in the four-fan Tandem Fan aircraft. TOGW sensitivity to T/W for the RALS aircraft was nearly five times that of the L+L/C aircraft. The L+L/C aircraft had the lowest sensitivities to T/W and control provisions of all the study aircraft. Engine location (fore/aft thrust split) and the fact that lift engines are not used in cruise flight accounted for these low sensitivities (Appendix A).

Mission sensitivities were less variant between aircraft designed for similar missions. Like design sensitivities, the significant mission sensitivities occurred for thrust margin and propulsion control provision variations. Mission sensitivities to horizontal and vertical tail size and empty weight variation were small. Comparison between aircraft designed for different missions was not possible because different mission parametrics were used (e.g. time on station vs. radius of action).

Modal characteristics of the aircraft were similar at 35 knots despite large differences in individual stability derivatives. At higher airspeed the aircraft modal characteristics were highly configuration specific (Appendix B). Low speed gust sensitivities were dominated by inlet ram forces. The tilt nacelle aircraft was two to three times more sensitive to horizontal gusts (X_u) than the other aircraft. The Tilt Nacelle and Tandem Fan aircraft were almost twice as sensitive to lateral and vertical gusts (Y_v and Z_w respectively) than the supersonic aircraft.

The impact of simultaneous control power provisions for all control axes was illustrated by showing the difference in design TOGW required to satisfy two levels of control power. These levels represented a range of interest for this study. (Individual axis control power usage in flight simulation tests (ref. 6) were shown to fall within this range.) The most important result shown by this approach was the severe penalty of simultaneous control provisions on designs using a common effector for control in more than one axis. This effect was more severe on the subsonic fan-powered airplanes than on the supersonic airplanes. However, subsequent analysis of flight simulation test data from reference 6 indicated that total control used by a common effector was a root sum of squares of separate axis requirements rather than a simple sum. This result would significantly reduce the penalty on the subsonic aircraft. More importantly, the result illustrated the importance of satisfactory control power criteria in evaluating different aircraft configuration and control concepts.

7.0 RECOMMENDATIONS

1. The design sensitivity procedures defined by this study should be considered from two standpoints.

   (1) Feasibility for evaluation of contractor designs

   (2) Inhouse or contractor supported evaluation of sensitivity of new or modified flying qulities criteria

2. Development of satisfacatory VTOL control power (and related) criteria should be given high priority.

8.0 REFERENCES

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9.0 SYMBOLS AND NOMENCLATURE

Symbols

C_i	General form for stability derivatives (derivatives includes mass or inertia); $C = X, Y, Z, L, M, N$; $i = u, v, w, p, g, r$
$\Delta F_G/F_G$, $\Delta T/T$	Fractional amount of thrust for control modulation.
i_T	Tail incidence.
S_{HT}, S_{VT}	Horizontal and vertical tail area respectively.
SM	Static margin.
t_{double}	Time to double amplitude.
V_{con}	Conversion speed
V_{STALL}, V_s	Stall speed.
α_T	Tail angle of attack.
σ	Standard deviation; real component of root, $s = \sigma + i\omega$
ζ	Damping ratio.
ω	Frequency; imaginary component of root, $s = \sigma + i\omega$
ω_n	Natural frequency.
λ	An eigenvalue

Frequently Used Abbreviations

ASW	Antisubmarine Warfare
CP	Control Power
DLI	Deck Launched Intercept
FCS	Flight Control System
R/A	Radius of Action
RALS	Remote Augmented Lift System
T/W	Thrust-to-Weight Ratio
TOGW	Takeoff Gross Weight
TOS	Time On Station
VATOL	Vertical Attitude Takeoff and Landing
VIGV	Variable Inlet Guide Vanes
VTAC	VSTOL Technology Assessment Committee

APPENDIX A
DESIGN SYNTHESIS SUMMARY

Four V/STOL airplane designs were developed for an analysis of design sensitivity to flying qualities. The particular airplane concepts represented by these designs were selected to span a generic range of propulsion systems and configuration arrangements which appeared to have near-term development potential. Two of the airplanes, a four-poster Tandem Fan and a two-poster Tilt Nacelle configuration, were designed for the high altitude ASW mission defined in reference A1. The other two airplanes, a jet lift plus lift-cruise configuration and a RALS (Remote Auxiliary Lift System) configuration were designed for the supersonic DLI mission defined in reference A2.

Synthesis of the four airplane designs and selections of final baseline point designs were accomplished with the aid of Vought's ASAP (Aircraft Synthesis and Analysis Program). This computer routine integrates the aerodynamic, performance, weights, propulsion, and design analysis procedures and is ideally suited for the parametric design development required for this particular study. Parametric weight estimate procedures assumed 1990 technology levels.

Primary technology advances assumed were:

- Level II composite application
- Reduced weight core engines
- Advanced fan materials
- Lighter advanced modular avionics
- High pressure hydraulics
- Advanced DC electrical system
- Advanced air conditioning system

Three additional factors in the design and weight estimates were:

- o Weight penalties for reliability and maintainability were included and are listed as line items in weight breakdowns.
- o All composite material applications involved inspectable and/or replaceable assemblies (i.e., there are no buried composites).
- o Avionics weights were based on recent detailed estimates derived in conjunction with study participants from the avionics industry.

Weight and size characteristics of the final point selections are summarized in Table A-1, and more detailed group weight breakdowns and inertia characteristics are presented in Table A-2. Key design constraints and parametric relationships involved in selection of each point design are summarized in the following sections (A.1 through A.4).

A.1 TANDEM FAN

Results of Vought's previous studies of the tandem fan airplane have shown that TOGW (takeoff gross weight) is insensitive to wing area and aspect ratio for the selected mission constraints, so the wing design was fixed in this study at an aspect ratio of 7.0 and area of 450 ft^2. In addition a fan design pressure ratio of 1.5 was selected on the basis of previous optimization studies. Then the remaining problem was sizing the airplane and propulsion system to satisfy the takeoff T/W and control power requirements assumed for initial point design selection. Thrust modulation of $\pm 27\%$ was estimated to meet the control requirements.

The tandem fan system mixes flow from the aft fan and the core engine exhaust in the aft nozzle. A characteristic result of this mixed flow system

TABLE A-1

SUMMARY COMPARISON OF POINT DESIGN SELECTIONS

AIRPLANE	TANDEM FAN	TILT NACELLE	L + L/C	RALS
TOGW, lb	40,954	43,607	42,163	46,904
WEIGHT EMPTY, lb	25,556	26,868	24,560	27,913
WING AR	7	7	4	2.8
WING, AREA, ft^2	450	358/219 (1)	377	426
WING LOADING (TO), lb/ft^2	91	76 (2)	112	110
TAKEOFF T/W	1.05	1.05	1.05	1.14 (3)
FAN DIAM, inches	45.7	66.0	-	-
VTO THRUST SPLIT, %	48/52	-	60/40	41/59

NOTES: (1) FORWARD/AFT "WINGS"

(2) BASED ON TOTAL AREA OF BOTH WINGS

(3) PROVISION OF PITCH CONTROL REQUIRED 1.14 T/W; THEREFORE THE HIGHER T/W (1.14 VICE 1.05) WAS USED.

TABLE A-2

POINT DESIGN WEIGHT SUMMARIES AND MASS PROPERTY DATA

	TYPE A TANDEM FAN ASW (STO)	TYPE A TILT NACELLE ASW (STO)	TYPE B PALS	TYPE B LIFT + LIFT CRUISE
STRUCTURE	(10,463)	(10,136)	(10,363)	(10,166)
Wing	2,342	2,414	2,118	2,439
Tail	650	1,125	755	884
Body	3,368	4,010	3,588	3,662
Landing Gear	1,407	1,472	1,659	1,638
Engine Section	2,696	1,115	2,243	1,543
PROPULSION	(7,713)	(9,504)	(12,749)	(9,568)
L/C Engines	3,915	5,301	6,714	4,033
Lift Engines	0	0	0	1,485
Fans	1,772	2,309	0	0
Transmission-Mechanical	0	0	0	0
Gas Duct System	0	402	1,339	270
Exhaust	933	186	3,224	2,315
Fuel System	793	1,006	1,143	1,106
Controls & Starting	200	200	179	209
Accessory Gearbox	100	100	150	150
SYSTEMS & EQUIPMENT	(7,380)	(7,228)	(4,801)	(4,826)
Flight Controls & Hyd.	1,184	1,031	941	967
Aux. Power Unit	200	200	100	100
Instruments	170	170	130	130
Electrical	600	600	456	456
Avionics	3,000	3,000	1,888	1,888
Furnishings	700	700	260	260
Air Cond. & Anti-Ice	650	650	347	347
Handling	16	17	17	16
Reliability & Maintainability Provisions	550	550	250	250
Armament	310	310	412	412
WEIGHT EMPTY	(25,556)	(26,868)	(27,913)	(24,560)

TABLE A-2

POINT DESIGN WEIGHT SUMMARIES AND MASS PROPERTY DATA (CONTINUED)

	TYPE A TANDEM FAN ASW (STO)	TYPE A TILT NACELLE ASW (STO)	TYPE B RALS	TYPE B LIFT + LIFT CRUISE
USEFUL LOAD				
Crew	600	600	200	200
Fuel - Usable	10,720	12,047	15,219	13,828
Fuel - Unusable	108	121	153	139
Oil	60	60	120	120
Torpedoes	2,120	2,120	0	0
Sonobouys	1,125	1,125	0	0
Sonobouy Containers	400	400	0	0
Missiles	0	0	2,228	2,228
Weapon Suspension	100	100	570	570
Survival Equip. & Miscellaneous	165	165	42	42
Cannon (M61-A1)	0	0	250	250
Ammunition (400 Rnds., 20mm)	0	0	208	226
TAKEOFF GROSS WEIGHT - LBS.	[40,954]	[43,606]	[46,903]	[42,163]
FLIGHT DESIGN GROSS WEIGHT	36,666	38,787	40,815	36,631
ECPR WEIGHT	12,575	13,252	11,265	13,833
ULTIMATE MANEUVER LOAD FACTOR (NZ)	5.25	5.25	11.25	11.25
*INERTIA & CENTER OF GRAVITY				
Emergency Landing Condition - WT (LBS)	(27,989)	(28,814)	(28,226)	(27,107)
IXX	39,056	56,557	21,230	21,396
IYY	90,446	81,492	147,925	128,407
IZZ	115,376	112,165	161,772	143,361
IXZ	4,080	5,436	6,496	5,846
X c.g.	400	421	501	477
Z c.g.	69	54	32	28
Normal Landing Condition - WT (LBS)	(31,234)	(32,559)	(31,024)	(29,335)
IXX	41,027	57,107	22,154	21,898
IYY	76,227	84,197	150,464	130,266
IZZ	113,579	114,260	162,887	144,725
IXZ	3,953	6,105	6,642	6,042
X c.g.	400	420	500	476
Z c.g.	62	50	29	26

*Inertia in Slug Ft.^{2}

c.g. reference axis ~pilots eye at X = 200

~bottom of fuselage at Z = 0

TABLE A-2

POINT DESIGN WEIGHT SUMMARIES AND MASS PROPERTY DATA (CONCLUDED)

	TYPE A TANDEM FAN ASW (STO)	TYPE A TILT NACELLE ASW (STO)	TYPE B RALS	TYPE B LIFT + LIFT/CRUISE
*INERTIAS & CENTER OF GRAVITY (CONT'D)				
Flight Design Condition - WT (LBS)	(36,666)	(38,787)	(38,336)	(36,632)
IXX	45,961	57,458	22,616	22,646
IYY	92,452	85,068	154,618	132,699
IZZ	117,059	114,528	167,542	147,381
IXZ	3,926	6,097	6,813	6,038
X c.g.	400	420	502	476
Z c.g.	67	50	30	24
Normal Takeoff Condition - Wt (LBS)	(40,954)	(43,606)	(46,903)	(42,163)
IXX	50,419	63,070	25,847	37,403
IYY	93,763	85,728	159,695	133,573
IZZ	121,659	120,887	175,388	162,973
IXZ	3,911	6,835	6,879	6,130
X c.g.	400	417	505	479
Z c.g.	71	49	30	25

*Inertia in Slug Ft.^{2}
c.g. reference axis ~ pilots eye at X = 200
~ bottom of fuselage at Z = 0

is that the optimum match between core engine size relative to fan size will vary with the level of thrust modulation provided. This characteristic is illustrated in Figure A-1 in terms of vertical thrust available as a function of the relative core size for various levels of thrust modulation available. In the lower range of the relative core size factor (from 1.2 to 1.3), the core engine power is not sufficient to drive the fans at their maximum speed. As the relative core size is increased, a maximum thrust level results when the core size is sufficient to obtain the maximum fan speed. When the core size is increased beyond this break, maximum fan speed is maintained but the core engine must be throttled below full power. This throttled operation of the oversized core engine produces a lower thrust contribution from the core exhaust stream and a reduction in total vertical thrust level results.

The effect of this optimum match between core engine size relative to fan size is reflected in the parametric TOGW carpet in Figure A-2. The basic carpet shows the variation of TOGW as a function of the Relative Core Size (RCS) factor and an Engine Scale Factor (ESF) which scales the entire propulsion system. The effect of the variation of vertical thrust available with RCS (From Figure A-1) is superimposed. The resulting point design airplane was selected on the $\pm 27\%$ thrust modulation line at an RCS factor of 1.35 and had a TOGW of 40,950 pounds. (The point design was selected at an RCS of 1.35 rather than the minimum TOGW of 40,750 pounds at an RCS of 1.33 for expediency in this study, since detailed propulsion system data were available for the RCS factor of 1.35 in the parametric.)

A.2 TILT NACELLE BASELINE SYNTHESIS

The tandem wing configuration for the tilt nacelle airplane was defined from previous work on this concept. Representative wing-tail sizes and aspect ratios were selected and fixed, since design for the subsonic ASW mission is more sensitive to propulsion system requirements than wing size and aspect ratio. Vertical mode propulsion control provisions estimated for this airplane were ±21.5% thrust modulation of the two fans for heave and roll control, and pitch reaction control from engine bleed equivalent to about 7% T/W. Due to the magnitude of the pitch control requirement, the reaction system was designed to always produce vertical thrust.

An extensive matrix of propulsion systems was developed to select the best combination of fan pressure ratio and relative core size for this design. The parametric design summary in Figure A-3 shows the baseline design selection at a fan pressure ratio of 1.5 and a relative core size (RCS) factor of 1.75. The reference for this RCS factor is consistent with that used in the tandem fan system. In the tilt nacelle systems, an RCS factor of 1.4 represents the minimum size engine required to drive the fans at their maximum operating speed.

Obviously (from Figure A-3) high engine bleed requirements drive this system to a large core engine and high fan pressure ratios.

A.3 LIFT PLUS LIFT/CRUISE BASELINE SYNTHESIS

The geometrical arrangement of the lift plus lift/cruise (L + L/C) airplane required a 60%/40% thrust split between the forward lift engines and aft cruise engines for pitch balance in the vertical mode. This thrust split and the fact that this concept does not use the lift engines in cruise resulted in some design sensitivities that were significantly different from other airplanes in the study. Reasons for these different sensitivities are explained in the following summary of the baseline design selection.

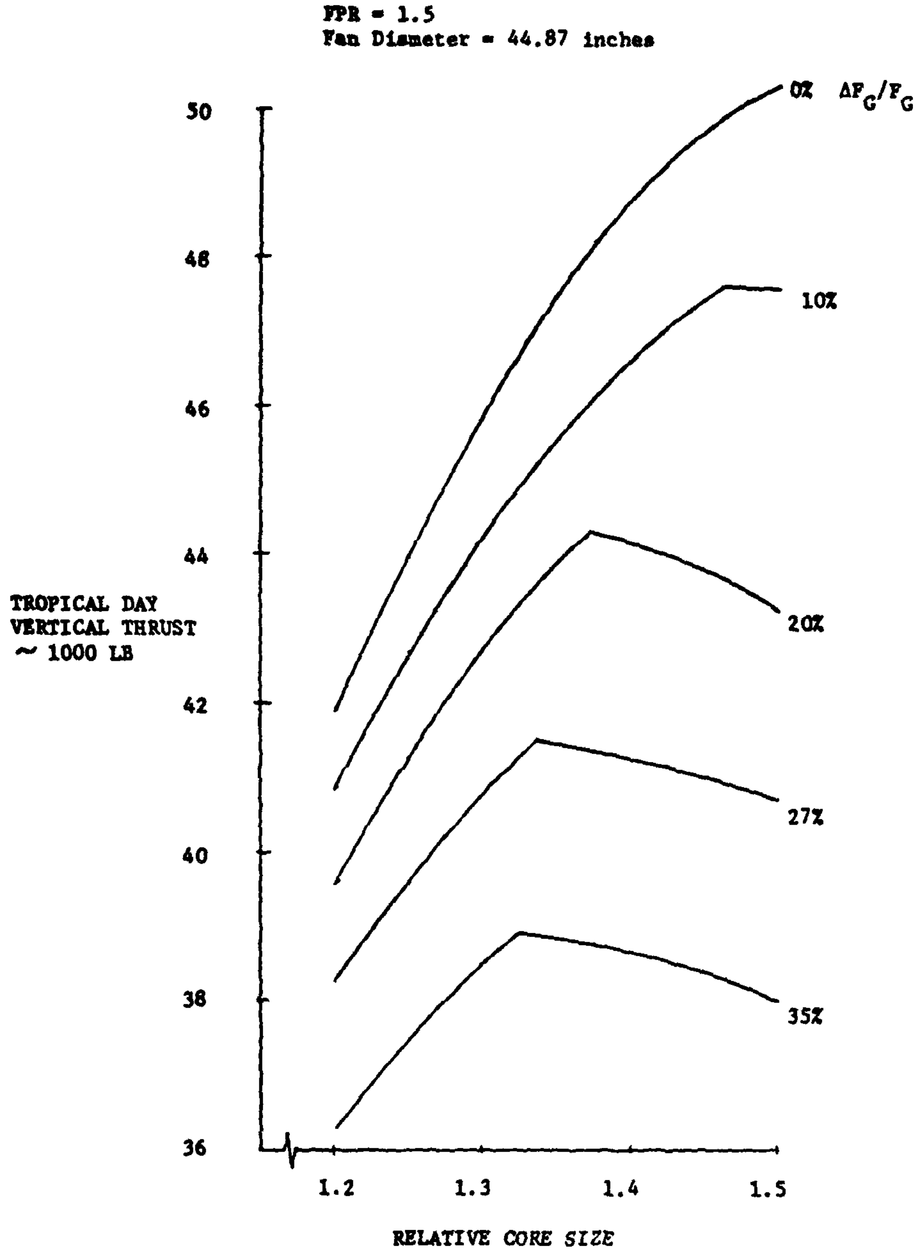


Figure A-1. Tandem Fan VTO Thrust Characteristics

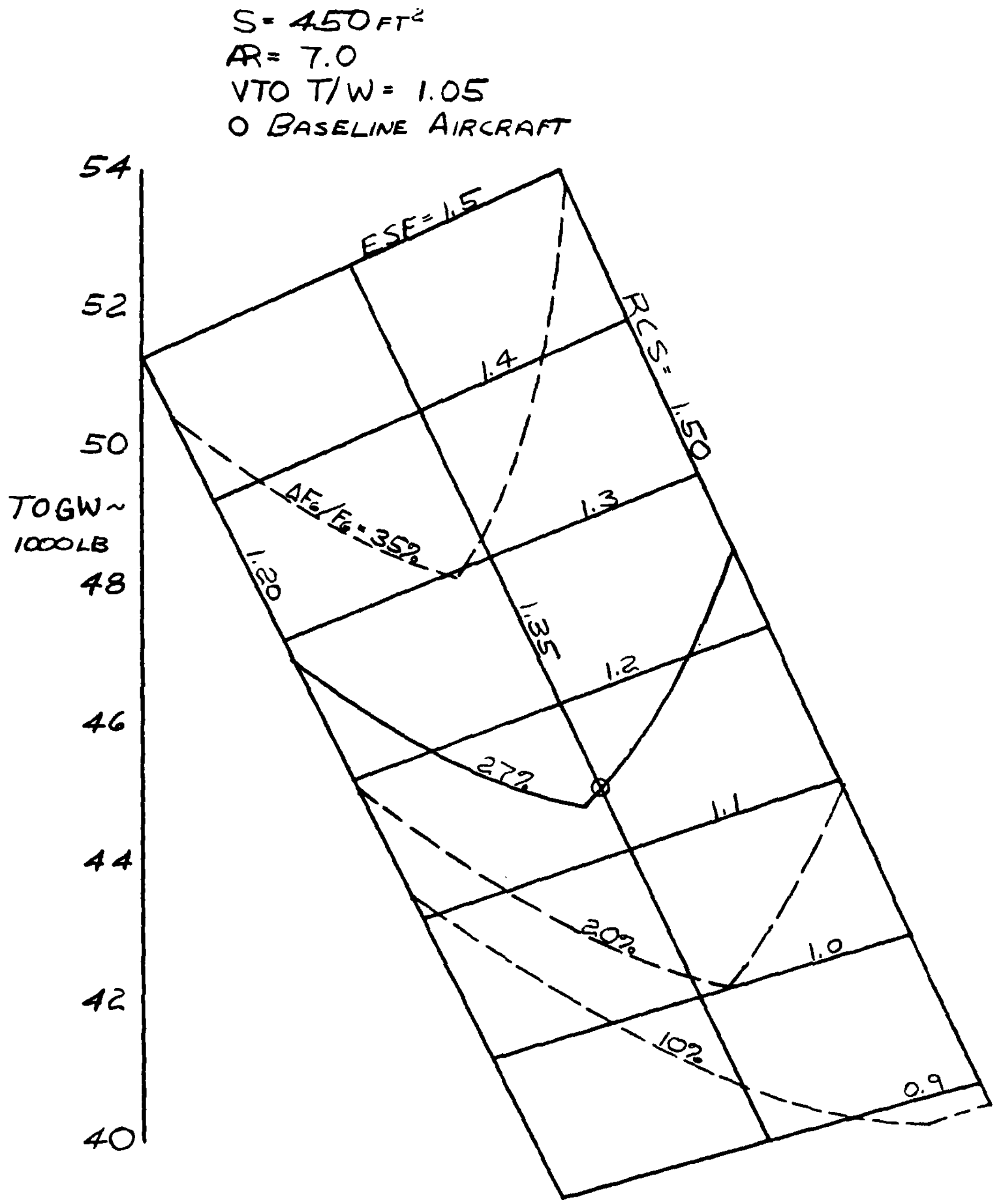


Figure A-2. Tandem Fan Sizing Parametric

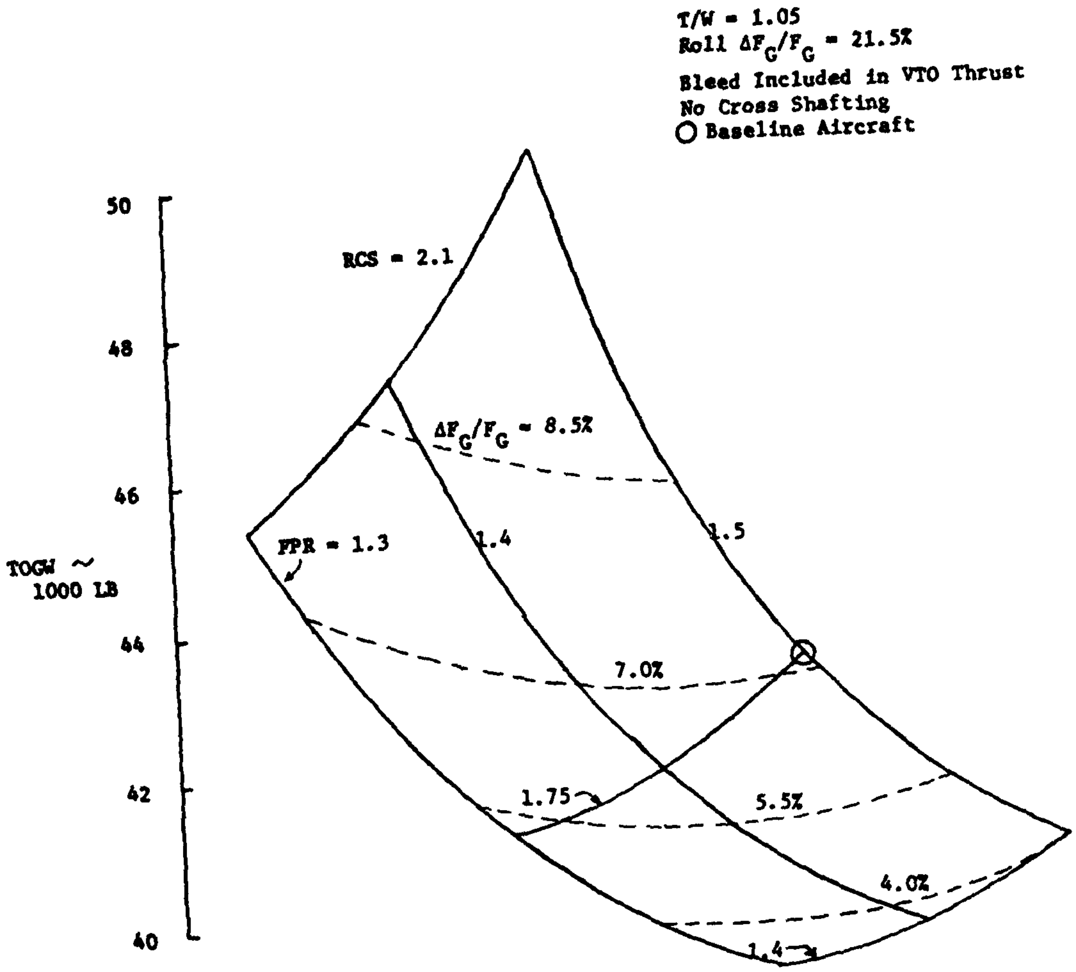
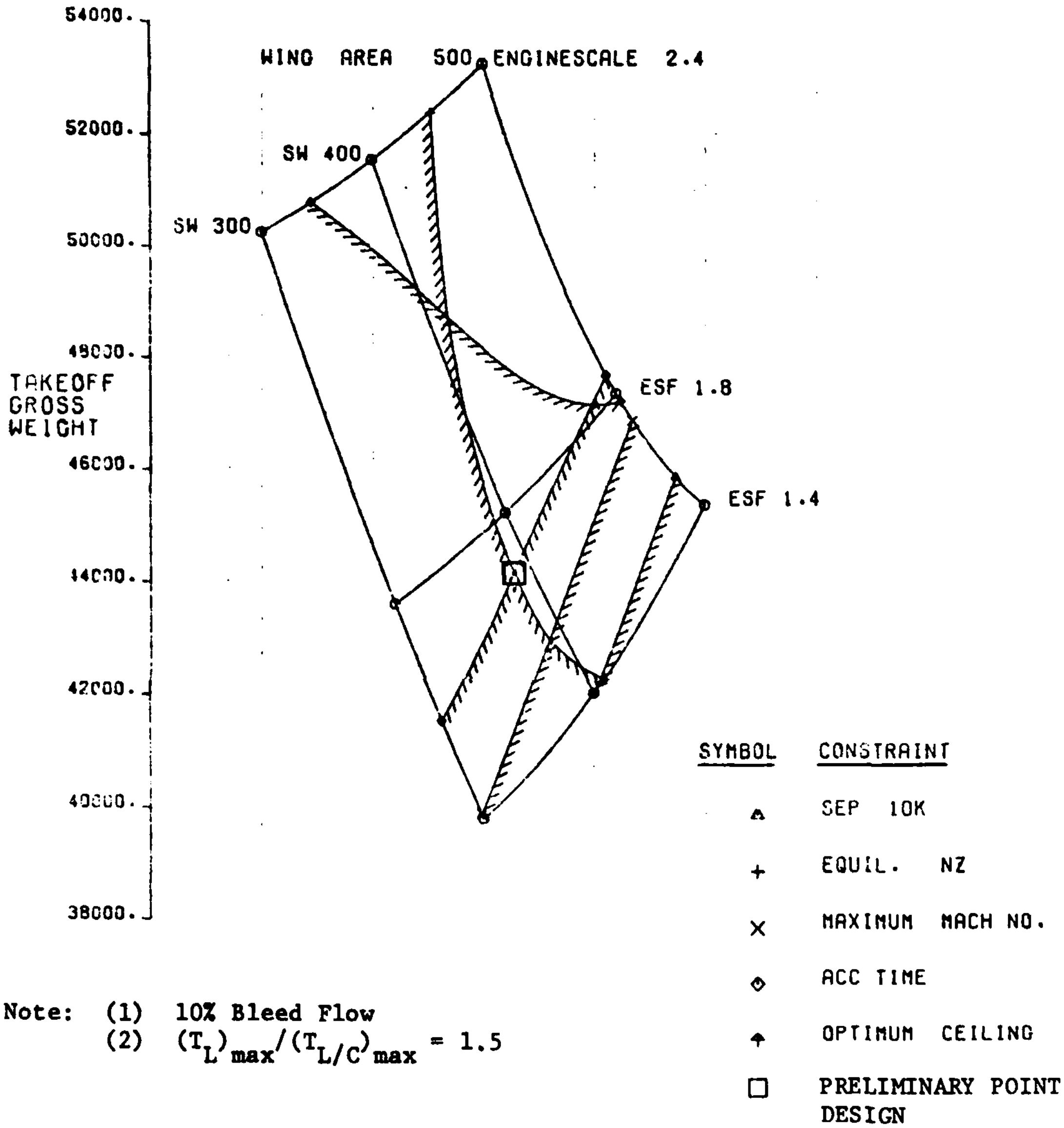


Figure A-3. Parametric Design Summary for Tilt Nacelle Airplane

A basic result of the thrust split is that the cruise engines must be sized to meet the supersonic mission requirements. If the lift engines are sized to use maximum intermediate thrust from the cruise engines in the vertical mode, then the airplane has a very high T/W. An example of a point design selection for this case is shown on Figure A-4. In this example the minimum TOGW point design was selected to satisfy turn performance and acceleration time constraints, resulting in a TOGW of 44,098 pounds and a wing area of 388 ft^2. This point design had a ceiling 1400 feet below the desired ceiling constraint, which was assumed to be an acceptable compromise to save about 3000 pounds TOGW. But the takeoff T/W of this airplane was 1.545 as a result of sizing the lift engines so that full thrust of the cruise engines could be used in the vertical mode. The effect of reducing the size of the lift engines relative to the cruise engines on TOGW is shown on Figure A-5 for varying levels of bleed air extraction for reaction control. Considering the T/W and control power guidelines assumed for this study, the final baseline design selection required 16% lift engine bleed for reaction control with a T/W of 1.05 and had a TOGW of 42,163 pounds. In this case the usable thrust from the cruise engine in the vertical mode would be limited to about 67% of maximum intermediate thrust in order to maintain static pitch balance.

A.4 RALS BASELINE SYNTHESIS

The RALS airplane concept provides VTO roll control from a reaction control system and pitch control by differential modulation of thrust from the main fore and aft nozzles. The basic relation for bleed flow distribution between the front RALS nozzles and reaction control is shown in Figure A-6. Meeting the design guidelines for control provisions required an engine bleed flow rate of 30 pounds/sec resulting in a 41%/59% VTO thrust split between the fore and aft nozzles.

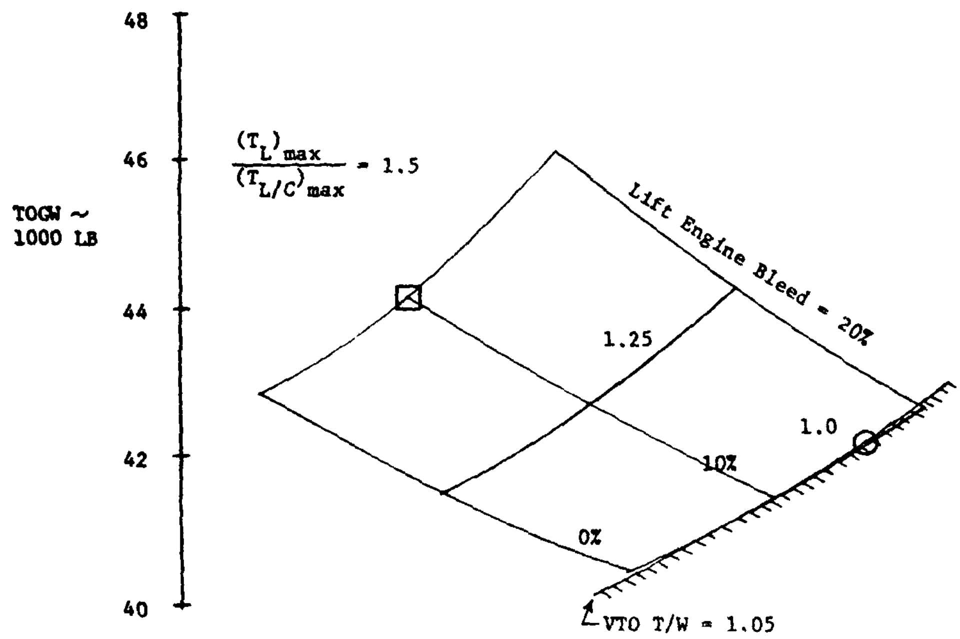


Note: (1) 10% Bleed Flow
(2) $(T_L)_{max}/(T_{L/C})_{max} = 1.5$

Figure A-4. Lift + Lift/Cruise Sizing Parametric

Thrust Vector Geometry: c.g. to lift engine = 160 inches
c.g. to cruise engine = 240 inches

□ Point design from Figure A-4
○ Baseline airplane



NOTE: (1) For V-mode pitch balance, usable $T_{L/C} \doteq T_L/1.5$

(2) When $(T_L)_{max}/(T_{L/C})_{max} < 1.5$, cruise engine is limited to partial throttle operation

Figure A-5. Effect of Lift Engine Size and Bleed Flow on TOGW for the Lift + Lift/Cruise Airplane

Provision of pitch control by fore and aft thrust modulation required the equivalent of a 1.14 T/W ratio just for pitch control. (Note that Table A-1 reflects selection of the higher takeoff T/W requirement for RALS). This requirement and the combat maneuver capability requirement were the constraining factors in sizing the baseline design as shown in Figure A-7.

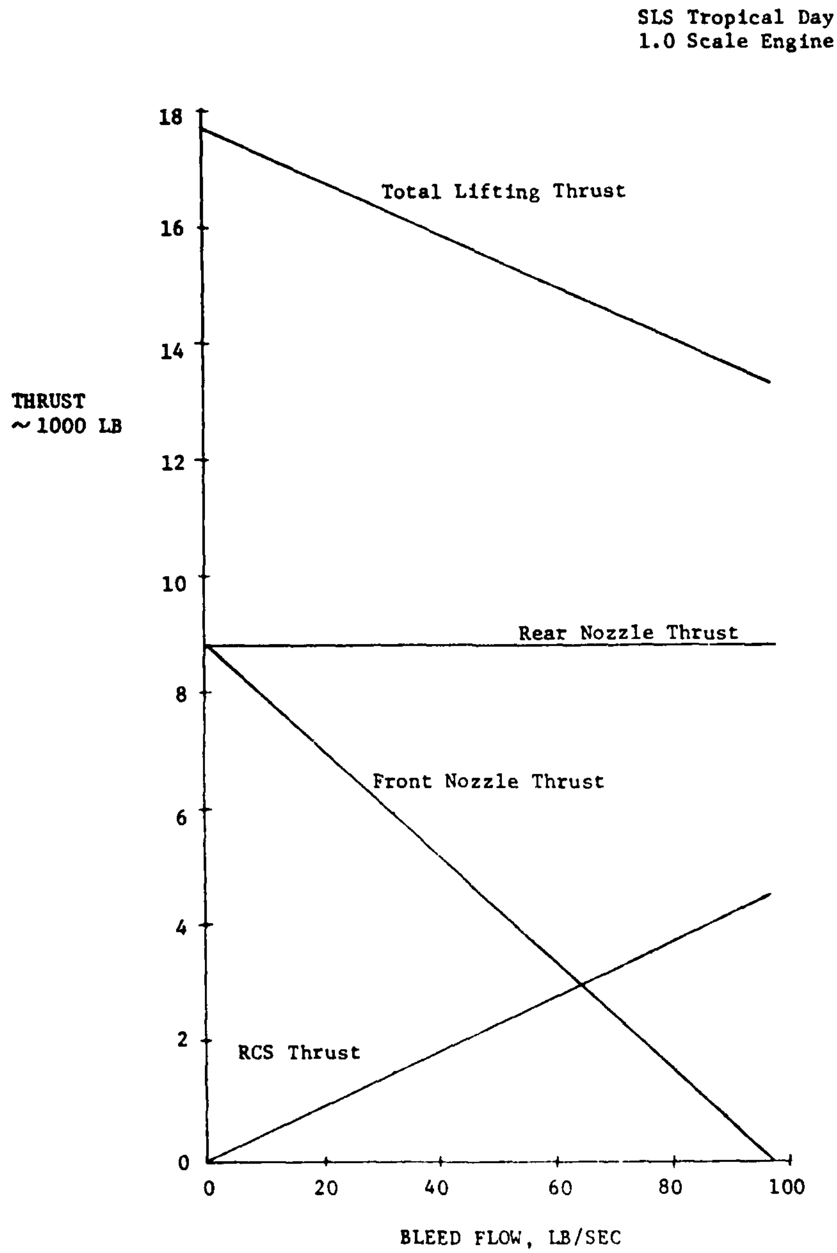


Figure A-6. RALS Distribution Between Forward and Aft Nozzles and the RCS for Varying Bleed Flow Rates

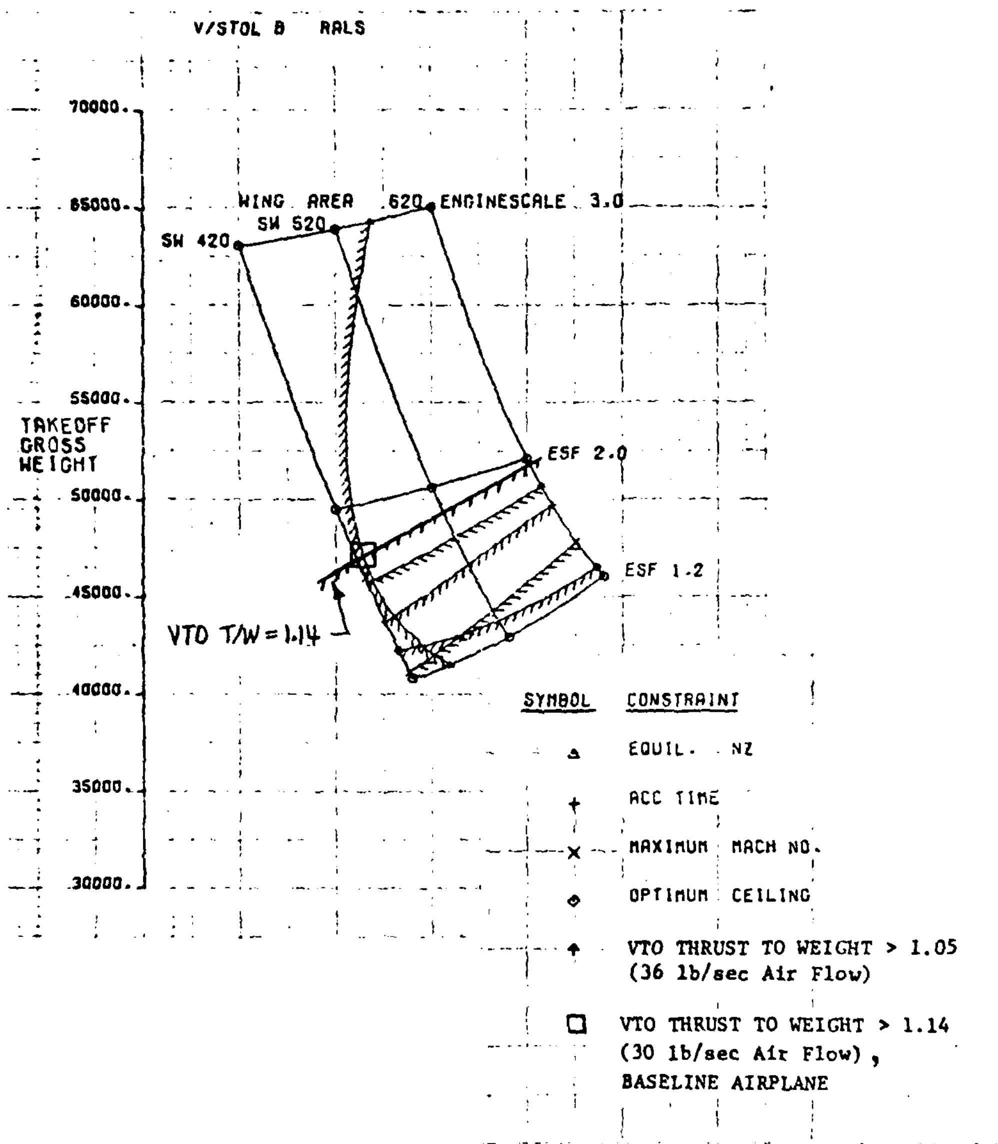


Figure A-7. TOGW Variation With Wing Area and Engine Scale Factor for the RALS Airplane

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APPENDIX B

COMPENDIUM OF DATA FOR FOUR GENERIC V/STOL AIRPLANES

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B.0 INTRODUCTION AND DATA PRESENTATION FORMAT

This Appendix summarizes power off aerodynamics, thrust-induced effects, and trim data for the four study aircraft. Sections B.1 through B.4 provide data for the Tandem Fan, Tilt Nacelle, Lift plus Lift/Cruise (L + L/C), and RALS airplanes in that order. Each section includes the following data:

1. Power off aerodynamics data in stability axes - Data plots are given for C_L vs α, C_m vs C_L, and C_D vs C_L for $0 \leq \alpha \leq 30$ deg at appropriate tail, elevon, flap and/or elevator deflections; C_{Y_β}, C_{l_β}, and C_{n_β} vs α for $0 \leq \alpha \leq 30$ deg; C_L, C_m and C_D vs α for -180 deg $\leq \alpha \leq 180$ deg; and C_Y, C_l, and C_n vs β for 0 deg $\leq \beta \leq 90$ deg at $\alpha = 0$ deg. These data were calculated by the generic V/STOL aerodynamics model described in reference (B-a) which is based on the model of reference (B-b). The coefficients for this model were calculated by application of the digital DATCOM program (reference (B-c)) to the study aircraft.

2. Thrust-induced effects data - Models for the effects of thrust on the longitudinal aerodynamics are provided. Because of their highly configuration specific nature and lack of appropriate data, lateral directional thrust-induced effects were not included in the simulation math models of the four aircraft.

3. Trim Summary - Three tables per aircraft summarize thirteen representative trim conditions chosen from the hover and low speed, forward flight, and cruise flight regimes. ("Forward flight" encompasses airspeeds from 35 kt to V_{CON} per MIL-F-83300 convention.) The first table gives trim values for important aircraft state and control variables and longitudinal and lateral-directional modal characteristics. The second and third tables provide longitudinal and lateral directional dimensional body axis stability derivatives about the trim conditions. Trim conditions represented by the table are:

   - Headwind and 45 and 90 degree crosswind conditions in a hover in a 35 kt wind at landing weight.
   - 40, 80, and 120 kt conditions in level attitude ($\theta = 0$ deg) level forward flight ($\gamma = 0$ deg). Both landing and takeoff weight conditions are included.
   - 120 and 160 kt conditions in level forward flight at 4 deg attitude at landing weight.
   - 200 kt level cruise flight with flaps down at landing weight.
   - 1.4 V_S level cruise flight with flaps up at flight design weight.

Plots of cruise flight trim variables and modal characteristics and forward flight trim variables are also included in the trim data summary. Accompanying each set of trim summary data is a series of notes which highlight configuration specific aspects of the data.

Details of the control concept, geometry and mass properties for each airplane are provided in the main text and, unless required for clarification, will not be repeated here.

B.1 Tandem Fan Airplane Data

B.1.1 Tandem Fan Power Off Aerodynamics Data

Figures B.1.1 through B.1.4 summarize the power off aerodynamics of the Tandem Fan airplane. Horizontal tail incidence (i_H) is varied to trim the airplane in aerodynamic flight and is geared to fore-aft thrust balance in the forward and hover flight regimes. The wing trailing edge flap (δ_{TEF}) is deflected 30 deg to establish the flaps down configuration of the airplane.

B.1.2 Tandem Fan Thrust-Induced Effects

The Tandem Fan thrust-induced model is based on data in references (B-d) and (B-e). The model calculations are as follows:

$$\Delta L_{TI} = \left(\frac{\Delta L}{T_{AFT}}\right) T_{AFT} + \left(\frac{\Delta L}{T_{FWD}}\right) T_{FWD}$$

$$\Delta D_{TI} = \left(\frac{\Delta D}{T_{AFT}}\right) T_{AFT}$$

$$\Delta M_{TI} = \left(\frac{\Delta M}{T_{AFT}\bar{c}_W}\right) T_{AFT}\bar{c}_W + 0.5\left(\frac{\Delta L}{T_{FWD}}\right) T_{FWD}\bar{c}_W$$

$$\epsilon_{PWR} = f\left[\delta_{NOZ}, (V_\infty/V_j)_{TOTAL}\right]$$

$$\left(\frac{\Delta L}{T_{AFT}}\right) = f\left[\delta_{NOZ}, (V_\infty/V_j)_{AFT}\right]$$

$$\left(\frac{\Delta D}{T_{AFT}}\right) = f\left[\delta_{NOZ}, (V_\infty/V_j)_{AFT}\right]$$

$$\left(\frac{\Delta M}{T_{AFT}\bar{c}_W}\right) = f\left[\delta_{NOZ}, (V_\infty/V_j)_{AFT}\right]$$

$$\left(\frac{\Delta L}{T_{FWD}}\right) = f\left[\delta_{NOZ}, (V_\infty/V_j)_{FWD}\right]$$

$$\left(V_\infty/V_j\right)_{TOTAL} = \sqrt{\frac{2\bar{q}(2\pi)\left(r_{e_{AFT}}^2 + r_{e_{FWD}}^2\right)}{T_{AFT} + T_{FWD}}}$$

$$\left(V_\infty/V_j\right)_{AFT} = \sqrt{\frac{2\bar{q}(2\pi)r_{e_{AFT}}^2}{T_{AFT}}}$$

$$\left(V_\infty/V_j\right)_{FWD} = \sqrt{\frac{2\bar{q}(2\pi)r_{e_{FWD}}^2}{T_{FWD}}}$$

where

ΔL_{TI}, ΔD_{TI}, and ΔM_{TI} are the thrust-induced lift, drag and pitching moment in the stability axis system. ΔL_{TI} and ΔD_{TI} have units of lb; ΔM_{TI} has units of ft lb

ϵ_{PWR} is the thrust-induced downwash angle at the horizontal tail, deg

δ_{NOZ} is the average nozzle deflection, deg

T_{AFT} is the sum of the two aft fan thrusts, lb

T_{FWD} is the sum of the two forward fan thrusts, lb

$\bar{q}$ is dynamic pressure, lb/ft^2

$r_{e_{AFT}}$ and $r_{e_{FWD}}$ are the equivalent radii of the aft and forward nozzles, respectively, ft.

$\bar{c}_W$ is the wing mean aerodynamic chord, ft

$(\Delta L/T_{AFT})$, $(\Delta D/T_{AFT})$, $(\Delta M/T_{AFT}\bar{c}_W)$, $(\Delta L/T_{FWD})$, and ϵ_{PWR} are plotted on figure B.1.5 as functions of δ_{NOZ} and the appropriate (V_∞/V_j).

B.1.3 Tandem Fan Trim Summary

Tables B.1.1 through B.1.3 and figures B.1.6 and B.1.7 constitute the Tandem Fan trim summary. The following notes clarify certain table entries which are configuration specific:

Table B.1.1 Trim And Modal Characteristics of Tandem Fan Airplane

PARAMETER / FLIGHT CONDITION	HOVER HEADWIND FLAPS DOWN	HOVER 45 DEG. CROSSWIND FLAPS DOWN	HOVER 90 DEG CROSSWIND FLAPS DOWN	FWD. FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT
- TRIM CHARACTERISTICS							
True Airspeed, kt	35.0	35.0	35.0	40.0	40.0	80.0	80.0
Pitch Angle, deg	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bank Angle, deg	0.0	-8.19	-12.65	0.0	0.0	0.0	0.0
Angle of Attack, deg	0.0	-8.11	-90.01	0.0	0.0	0.0	0.0
Sideslip Angle, deg	0.0	-44.42	-77.35	0.0	0.0	0.0	0.0
Total Thrust, lb	31519	32452	31747	31457	41555	28777	39997
Nozzle Deflection, deg	86.34	88.44	91.12	85.81	85.91	81.25	81.60
Pitch Trim Moment Appl. by Prop. Sys., ft-lb	-7237	1293	8973	-8745	-14895	-20263	-31269
Roll Trim Moment Appl. by Prop. Sys., ft-lb	0.0	-8922	-8535	0.0	0.0	0.0	0.0
Yaw Thrust Deflection, deg	0.0	-7.20	-8.96	0.0	0.0	0.0	0.0
Tail Incidence, deg	1.94	-0.03	-1.93	2.15	2.83	5.33	6.22

Table B.1.1 Trim and Modal Characteristics of Tandem Fan Airplane (Continued)

PARAMETER \ FLIGHT CONDITION	HOVER HEADWIND FLAPS DOWN	HOVER 45 DEG. CROSSWIND FLAPS DOWN	HOVER 90 DEG CROSSWIND FLAPS DOWN	FWD. FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT
- MODAL CHARACTERISTICS*							
Longitudinal	[0.138, 0.375; -0.346, 0.400] (-0.502) (-0.201)	[0.192, 0.392; -0.439, 0.437] (-0.413) (-0.278)	[0.105, 0.245; -0.395, 0.266] (-0.298) (-0.103)	(-1.141) (-0.124) (0.291) (0.472)	[0.373, 0.178; -0.903, 0.413] (-1.119) (-0.133)	[0.306, 0.273; -0.746, 0.410] (-1.429) (-0.174)	[0.231, 0.382; -0.517, 0.446] (-1.266) (-0.216)
Lateral	[0.223, 0.559; -0.371, 0.601] (-0.785) (-0.173)	[0.153, 0.478; -0.304, 0.502] (-0.703) (-0.103)	[0.181, 0.460; -0.366, 0.494] (-0.626) (-0.169)	[0.296, 0.434; -0.563, 0.526] (-0.955) (-0.204)	[0.319, 0.444; -0.584, 0.547] (-0.947) (-0.230)	[0.178, 0.589; -0.289, 0.615] (-1.177) (-0.160)	[0.183, 0.626; -0.280, 0.652] (-1.089) (-0.196)

* $[-\zeta\omega_n, \omega_n\sqrt{1-\zeta^2}; \zeta, \omega_n]$ indicates complex root pair located at $s = -\zeta\omega_n \pm j\omega_n\sqrt{1-\zeta^2}$ with natural frequency of ω_n rad/sec and damping ratio of ζ

(λ) indicates real root located at $s = \lambda$

Table B.1.1 Trim and Modal Characteristics of Tandem Fan Airplane (Continued)

FLIGHT CONDITION / PARAMETER	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT.	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 1.4 V_s FLAPS UP FLT. DES. WGT.
- TRIM CHARACTERISTICS						
True Airspeed, kt	120.0	120.0	120.0	160.0	200.0	186.2
Pitch Angle, deg	0.0	0.0	4.0	4.0	2.90	6.99
Bank Angle, deg	0.0	0.0	0.0	0.0	0.0	0.0
Angle of Attack, deg	0.0	0.0	4.0	4.0	2.90	6.99
Sideslip Angle, deg	0.0	0.0	0.0	0.0	0.0	0.0
Total Thrust, lb	21201	32010	13753	6085	6000	4027
Nozzle Deflection, deg	73.11	75.07	64.93	31.99	0.0	0.0
Pitch Trim Moment Appl. by Prop. Sys., ft-lb	-13702	-27182	-3584	5674	6623	4445
Roll Trim Moment Appl. by Prop. Sys., ft-lb	0.0	0.0	0.0	0.0	0.0	0.0
Yaw Thrust Deflection, deg	0.0	0.0	0.0	0.0	0.0	0.0
Tail Incidence, deg	6.18	7.73	4.95	0.04	0.49	0.49

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Table B.1.1 Trim and Modal Characteristics of Tandem Fan Airplane (Concluded)

PARAMETER \ FLIGHT CONDITION	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT.	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 1.4 V_s FLAPS UP FLT. DES. WGT.
- MODAL CHARACTERISTICS						
Longitudinal	[-0.155 0.216; 0.581, 0.226] (-1.338) (0.234)	[-0.0136, 0.0589; 0.225, 0.0605] [-0.720, 0.746; 0.694, 1.037]	[-0.243, 0.320; 0.604, 0.402] (-1.357) (0.377)	[-0.935, 0.429; 0.909, 1.028] (0.191) (-0.270)	[-0.0133, 0.113; 0.116, 0.114] [-1.518, 2.238; 0.561, 2.704]	[-0.00472, 0.116; 0.0408, 0.116] [-1.001, 1.124; 0.665, 1.505]
Lateral	[0.0463, 0.922; -0.0501, 0.923] (-1.415) (-0.0671)	[0.00425, 1.056; 0.00402, 1.056] (-1.204) (-0.0732)	[0.00734, 1.126; -0.00652, 1.126] (-1.377) (-0.0185)	[-0.0668, 1.561; 0.0428, 1.563] (-1.665) (0.00361)	[-0.228, 2.348; 0.0968, 2.359] (-1.968) (0.00593)	[-0.118, 1.837; 0.0643, 1.841] (-1.634) (0.00992)

Table B.1.2 Longitudinal Stability Derivatives of Tandem Fan Airplane

DERIVATIVE \ FLIGHT CONDITION	HOVER 35 KT HEADWIND FLAPS DOWN	HOVER 35 KT 45 DEG CROSSWIND FLAPS DOWN	HOVER 35 KT 90 DEG CROSSWIND FLAPS DOWN	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT
- X - DERIVATIVES							
X_u - ft/sec^2/ft/sec	-0.0357	-0.0387	-0.0283	-0.0359	-0.0348	-0.0436	-0.0368
X_w - ft/sec^2/ft/sec	-0.00218	-0.0216	-0.00140	-0.00237	-0.00449	-0.00265	-0.00737
X_q - ft/sec^2/rad/sec	-0.132	0.0124	0.100	-0.158	-0.200	-0.308	-0.396
X_{i_H} - ft/sec^2/rad	-0.110	0.0892	0.0303	-0.149	-0.193	-1.073	-1.392
$X_{\delta T_{PITCH}}$ - ft/sec^2/lb	0.0	0.00003	0.0	0.0	0.00002	-0.00006	0.00015
$X_{\delta_{NOZ}}$ - ft/sec^2/rad	-32.79	-33.41	-32.30	-32.76	-32.95	-30.17	-31.87
$X_{\delta T}$ - ft/sec^2/lb	0.00001	-0.00002	-0.00003	0.00001	0.0	0.00010	0.00004
- Z - DERIVATIVES							
Z_u - ft/sec^2/ft/sec	-0.00716	0.0157	0.00070	-0.00835	-0.00162	-0.0921	-0.0612
Z_w - ft/sec^2/ft/sec	-0.227	-0.177	-0.0930	-0.250	-0.211	-0.426	-0.356
Z_q - ft/sec^2/rad/sec	-1.302	-1.030	-0.809	-1.401	-1.517	-2.334	-2.614
Z_{i_H} - ft/sec^2/rad	-1.213	-0.300	0.00186	-1.651	-1.930	-9.334	-10.66
$Z_{\delta T_{PITCH}}$ - ft/sec^2/lb	0.00024	0.00016	0.0	0.00027	0.00037	0.00073	0.00176
$Z_{\delta_{NOZ}}$ - ft/sec^2/rad	-1.989	-1.011	0.415	-2.273	-2.251	-6.486	-5.094
$Z_{\delta T}$ - ft/sec^2/lb	-0.00405	-0.00401	-0.00399	-0.00405	-0.00307	-0.00359	-0.00262

Table B.1.2 Longitudinal Stability Derivatives of Tandem Fan Airplane (Continued)

DERIVATIVE \ FLIGHT CONDITION	HOVER 35 KT HEADWIND FLAPS DOWN	HOVER 35 KT 45 DEG CROSSWIND FLAPS DOWN	HOVER 35 KT 90 DEG CROSSWIND FLAPS DOWN	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT
- M - DERIVATIVES							
M_u - rad/sec^2/ft/sec	0.00257	0.00273	0.00069	0.00281	0.00384	0.00433	0.00530
M_w - rad/sec^2/ft/sec	0.0114	0.0132	0.00765	0.0114	0.0103	0.00592	0.00324
M_q - rad/sec^2/rad/sec	-0.164	-0.0932	-0.0703	-0.186	-0.223	-0.422	-0.507
M_{i_H} - rad/sec^2/rad	-0.311	-0.0939	-0.00389	-0.424	-0.525	-2.364	-2.852
$M_{\Delta T_{PITCH}}$ - rad/sec^2/lb	0.00047	0.00047	0.00048	0.00046	0.00043	0.00043	0.00065
$M_{\delta_{NOZ}}$ - rad/sec^2/rad	-0.243	-0.301	-0.445	-0.213	-0.271	0.145	-0.217
$M_{\Delta T}$ - rad/sec^2/lb	0.00001	0.0	-0.00002	0.00001	0.00001	0.0	0.00004

Table B.1.2 Longitudinal Stability Derivatives of Tandem Fan Airplane (Continued)

PARAMETER \ FLIGHT CONDITION	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT.	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 1.4 V_s FLAPS UP FLT. DES. WGT.
- X - DERIVATIVES						
X_u - $ft/sec^2/ft/sec$	-0.0447	-0.0455	-0.0304	-0.0249	-0.0255	-010105
X_w - $ft/sec^2/ft/sec$	0.00225	-0.00566	0.0593	0.0858	0.0819	0.130
X_q - $ft/sec^2/rad/sec$	-0.288	-0.435	-0.0827	0.0980	0.0759	0.276
X_{i_H} - $ft/sec^2/rad$	-2.514	-3.578	-1.749	-0.00652	-0.689	0.0998
$X_{\Delta T_{PITCH}}$ - $ft/sec^2/lb$	-0.00003	0.00042	-0.00016	-0.00047	-0.00009	-0.00011
$X_{\delta_{NOZ}}$ - $ft/sec^2/rad$	-22.77	-25.84	-13.90	-4.515	-1.028	-0.336
$X_{\Delta T}$ - $ft/sec^2/lb$	0.00036	0.00030	0.00094	0.00257	0.00276	0.00248
- Z - DERIVATIVES						
Z_u - $ft/sec^2/ft/sec$	-0.142	-0.105	-0.169	-0.157	-0.128	-0.0917
Z_w - $ft/sec^2/ft/sec$	-0.600	-0.496	-0.666	-0.868	-1.100	-0.872
Z_q - $ft/sec^2/rad/sec$	-2.844	-3.287	-2.407	-2.906	-5.397	-3.090
Z_{i_H} - $ft/sec^2/rad$	-21.49	-24.62	-20.36	-36.31	-85.10	-44.94
$Z_{\Delta T_{PITCH}}$ - $ft/sec^2/lb$	0.00123	0.00379	0.00093	0.00409	0.00082	0.00090
$Z_{\delta_{NOZ}}$ - $ft/sec^2/rad$	-14.92	-12.31	-15.43	-7.521	-15.01	-9.831
$Z_{\Delta T}$ - $ft/sec^2/lb$	-0.00355	-0.00220	-0.00339	-0.00307	-0.00086	-0.00103

Table B.1.2 Longitudinal Stability Derivatives of Tandem Fan Airplane (Concluded)

FLIGHT CONDITION / PARAMETER	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT.	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 1.4 V_s FLAPS UP FLT. DES. WGT.
- M - DERIVATIVES						
M_u - rad/sec^2/ft/sec	-0.00076	-0.00049	-0.00352	-0.00225	0.00070	0.00057
M_w - rad/sec^2/ft/sec	0.00161	-0.00348	0.00130	-0.00171	-0.0172	-0.00493
M_{q_b} - rad/sec^2/rad/sec	-0.600	-0.726	-0.574	-0.783	-1.446	-0.827
M_{i_H} - rad/sec^2/rad	-5.436	-6.531	-5.248	-9.809	-22.89	-11.85
$M_{\Delta T_{PITCH}}$ - rad/sec^2/lb	0.00040	0.00120	0.00036	0.00026	0.00014	0.00014
$M_{\delta_{NOZ}}$ - rad/sec^2/rad	0.456	0.327	0.531	0.00071	-0.104	-0.406
$M_{\Delta T}$ - rad/sec^2/lb	0.0	0.00017	0.00004	-0.00008	0.00005	0.00004

Table B.1.3 Lateral Stability Derivatives of Tandem Fan Airplane

DERIVATIVE \ FLIGHT CONDITION	HOVER 35 KT HEADWIND FLAPS DOWN	HOVER 35 KT 45 DEG CROSSWIND FLAPS DOWN	HOVER 35 KT 90 DEG CROSSWIND FLAPS DOWN	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT
- Y - DERIVATIVES							
Y_v - $ft/sec^2/ft/sec$	-0.0827	-0.159	-0.197	-0.0864	-0.0854	-0.101	-0.103
Y_p - $ft/sec^2/rad/sec$	-0.167	-0.152	-0.162	-0.179	-0.194	-0.272	-0.305
Y_r - $ft/sec^2/rad/sec$	1.000	0.954	0.963	1.038	1.091	1.295	1.427
Y_{δ_A} - $ft/sec^2/rad$	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$Y_{ST_{ROLL}}$ - $ft/sec^2/lb$	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Y_{δ_R} - $ft/sec^2/rad$	0.263	0.0559	0.0	0.344	0.393	1.375	1.573
$Y_{\delta_{YAW}}$ - $ft/sec^2/rad$	0.0	0.0	0.0	0.0	0.0	0.0	0.0
- L - DERIVATIVES							
L_v - $rad/sec^2/ft/sec$	-0.00832	-0.00512	-0.00455	-0.00906	-0.00921	-0.0141	-0.0143
L_p - $rad/sec^2/rad/sec$	-0.345	-0.262	-0.131	-0.389	-0.332	-0.740	-0.625
L_r - $rad/sec^2/rad/sec$	0.180	0.0360	0.100	0.197	0.196	0.326	0.323
L_{δ_A} - $rad/sec^2/rad$	-0.190	-0.118	0.0	-0.248	-0.202	-0.992	-0.807
$L_{ST_{ROLL}}$ - $rad/sec^2/lb$	0.00058	0.00057	0.00057	0.00058	0.00047	0.00058	0.00047
L_{δ_R} - $rad/sec^2/rad$	0.0415	0.00882	0.0	0.0542	0.0662	0.217	0.265
$L_{\delta_{YAW}}$ - $rad/sec^2/rad$	0.294	0.157	-0.0589	0.336	0.353	0.640	0.696

Table B.1.3 Lateral Stability Derivatives of Tandem Fan Airplane (Continued)

DERIVATIVE \ FLIGHT CONDITION	HOVER 35 KT HEADWIND FLAPS DOWN	HOVER 35 KT 45 DEG CROSSWIND FLAPS DOWN	HOVER 35 KT 90 DEG CROSSWIND FLAPS DOWN	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT
- N - DERIVATIVES							
N_v - rad/sec^2/ft/sec	-0.00435	-0.00426	-0.00320	-0.00408	-0.00441	-0.00029	0.00219
N_p - rad/sec^2/rad/sec	-0.00493	0.0294	0.00861	-0.00452	0.00115	-0.00068	0.0121
N_r - rad/sec^2/rad/sec	-0.0885	-0.0822	-0.109	-0.0957	-0.125	-0.150	-0.201
N_{δ_A} - rad/sec^2/rad	0.00199	0.00397	0.0	0.00260	0.00242	0.0104	0.00969
$N_{\Delta T_{ROLL}}$ - rad/sec^2/lb	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N_{δ_R} - rad/sec^2/rad	-0.0452	-0.0114	0.0	-0.0591	-0.0827	-0.236	-0.331
$N_{\delta_{YAW}}$ - rad/sec^2/rad	-1.662	-1.700	-1.656	-1.657	-2.044	-1.502	-1.951

Table B.1.3 Lateral Stability Derivatives of Tandem Fan Airplane (Continued)

DERIVATIVE \ FLIGHT CONDITION	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT.	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLT. 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLT. 1.4 V_S FLAPS UP FLT DES WGT
- Y - DERIVATIVES						
Y_v - ft/sec^2/ft/sec	-0.119	-0.119	-0.109	-0.128	-0.195	-0.123
Y_p - ft/sec^2/rad/sec	-0.349	-0.401	-0.328	-0.403	-0.743	-0.391
Y_r - ft/sec^2/rad/sec	1.408	1.622	1.217	1.313	2.337	1.235
Y_{δ_A} - ft/sec^2/rad	0.0	0.0	0.0	0.0	0.0	0.0
$Y_{\Delta T_{ROLL}}$ - ft/sec^2/lb	0.0	0.0	0.0	0.0	0.0	0.0
Y_{δ_R} - ft/sec^2/rad	3.094	3.540	3.079	5.474	12.86	6.252
$Y_{\delta_{YAW}}$ - ft/sec^2/rad	0.0	0.0	0.0	0.0	0.0	0.0
- L - DERIVATIVES						
L_v - rad/sec^2/ft/sec	-0.0192	-0.0192	-0.0203	-0.0260	-0.0373	-0.0267
L_p - rad/sec^2/rad/sec	-1.084	-0.911	-1.094	-1.444	-1.830	-1.508
L_r - rad/sec^2/rad/sec	0.442	0.436	0.678	0.876	1.081	0.843
L_{δ_A} - rad/sec^2/rad	-2.232	-1.816	-2.722	-4.840	-7.293	-5.957
$L_{\Delta T_{ROLL}}$ - rad/sec^2/lb	0.00056	0.00046	0.00054	0.00032	0.00001	0.00003
L_{δ_R} - rad/sec^2/rad	0.488	0.596	0.486	0.863	2.028	1.033
$L_{\delta_{YAW}}$ - rad/sec^2/rad	0.901	0.982	0.852	0.755	0.877	0.526

Table B.1.3 Lateral Stability Derivatives of Tandem Fan Airplane (Concluded)

DERIVATIVE \ FLIGHT CONDITION	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT.	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLT. 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLT. 1.4 V_s FLAPS UP FLT DES WGT
- N - DERIVATIVES						
N_v - rad/sec^2/ft/sec	0.00291	0.00484	0.00370	0.00668	0.0151	0.00757
N_p - rad/sec^2/rad/sec	0.00473	0.0250	-0.0666	-0.0854	-0.0295	-0.129
N_r - rad/sec^2/rad/sec	-0.198	-0.268	-0.192	-0.240	-0.421	-0.242
N_{δ_A} - rad/sec^2/rad	0.0234	0.0218	-0.00474	-0.00843	0.0100	-0.131
$N_{DT_{ROLL}}$ - rad/sec^2/lb	0.00002	0.00001	0.00004	0.00012	0.00014	0.00014
N_{δ_R} - rad/sec^2/rad	-0.532	-0.745	-0.529	-0.940	-2.210	-1.223
$N_{\delta_{YAW}}$ - rad/sec^2/rad	-1.072	-1.525	-0.658	-0.170	0.0	0.0

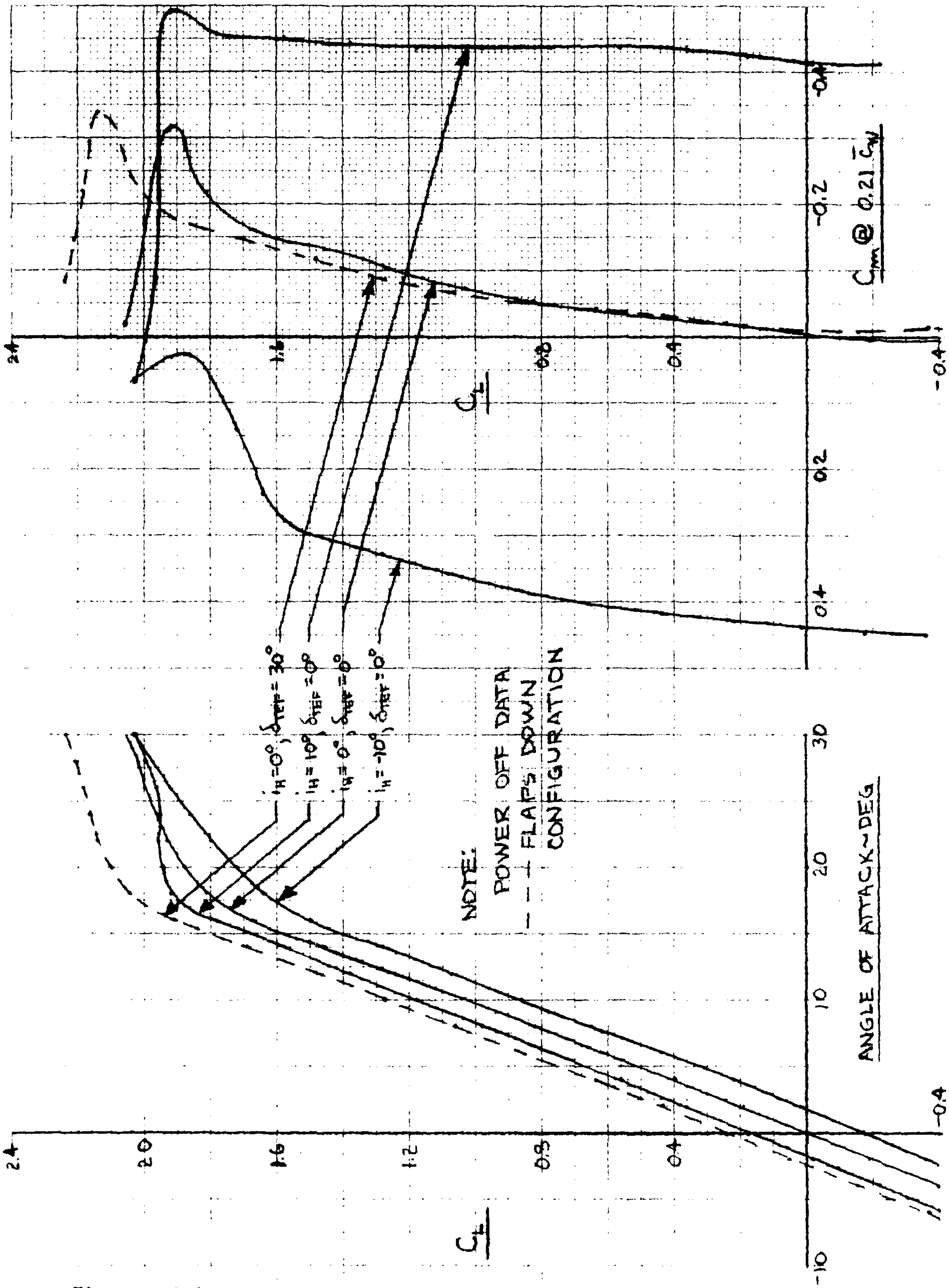


Figure B.1.1 - Tandem Fan Low Angle of Attack ($0 \leq \alpha \leq 30$ deg) Power Off Longitudinal Aerodynamic Characteristics

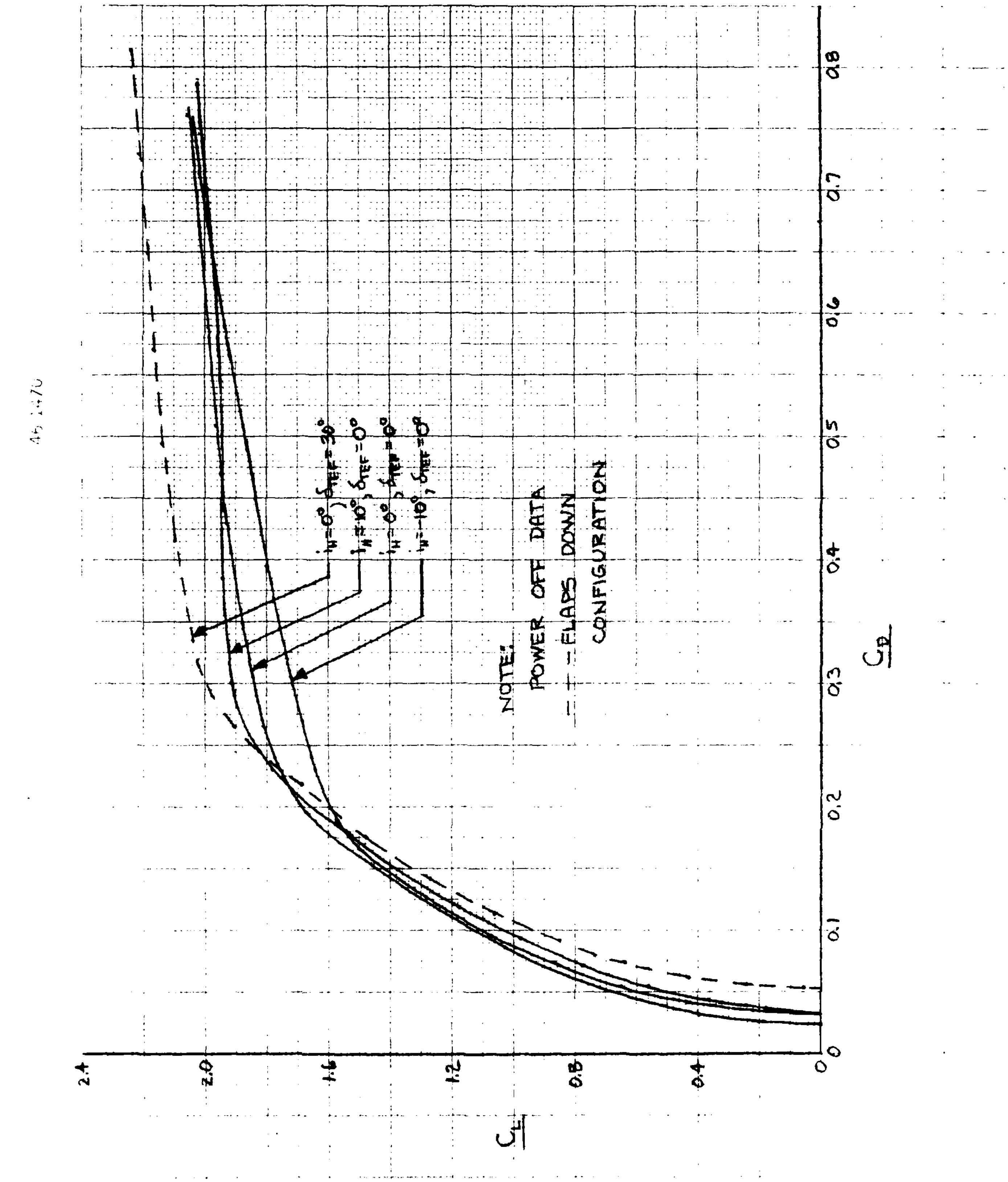


Figure B.1.1 (Cont.) - Tandem Fan Low Angle of Attack ($0 \leq \alpha \leq 30$ deg) Power Off Longitudinal Aerodynamic Characteristics

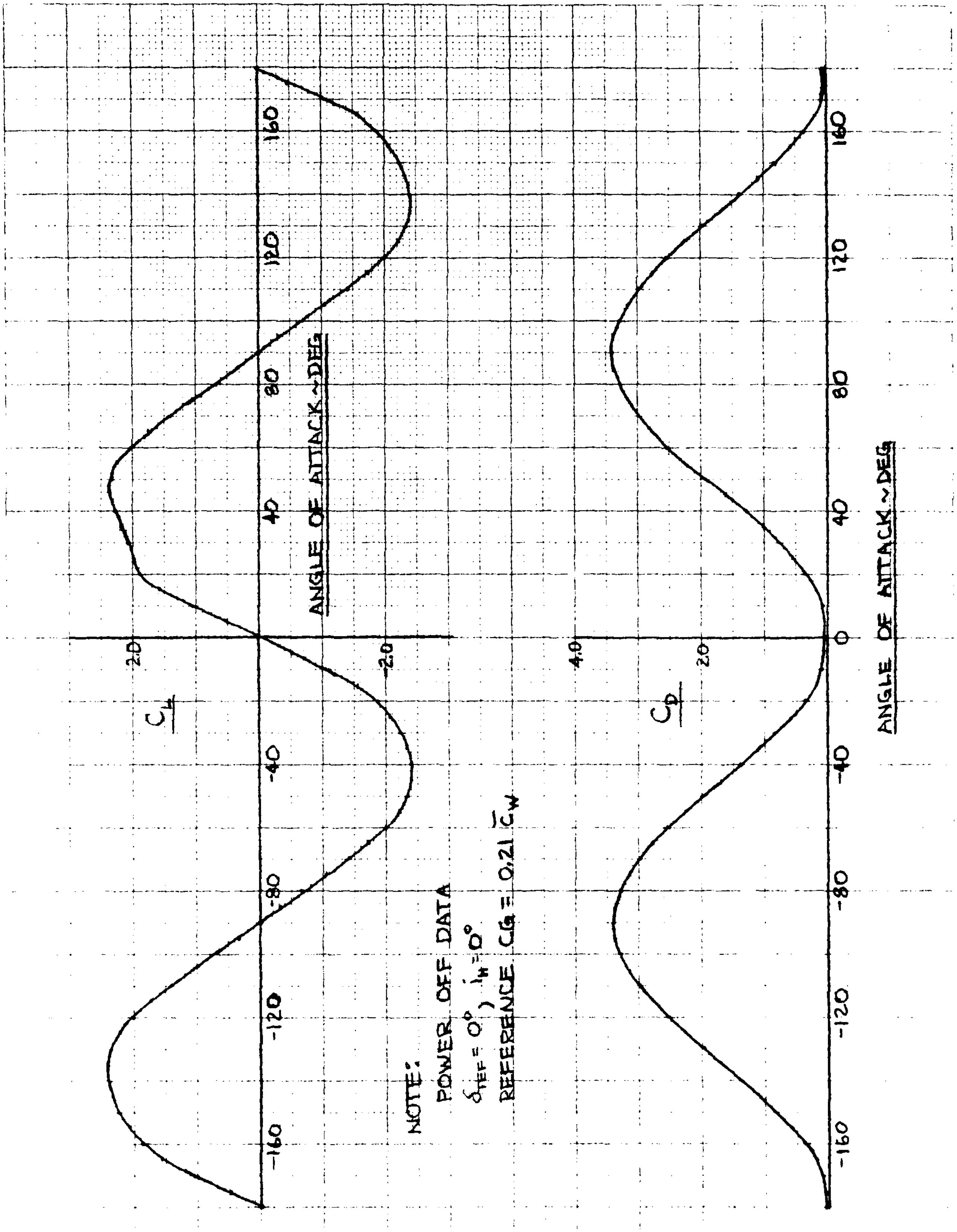


Figure B.1.2 - Tandem Fan High Angle of Attack (to $\pm$ 180 deg) Power Off Longitudinal Aerodynamics Characteristics

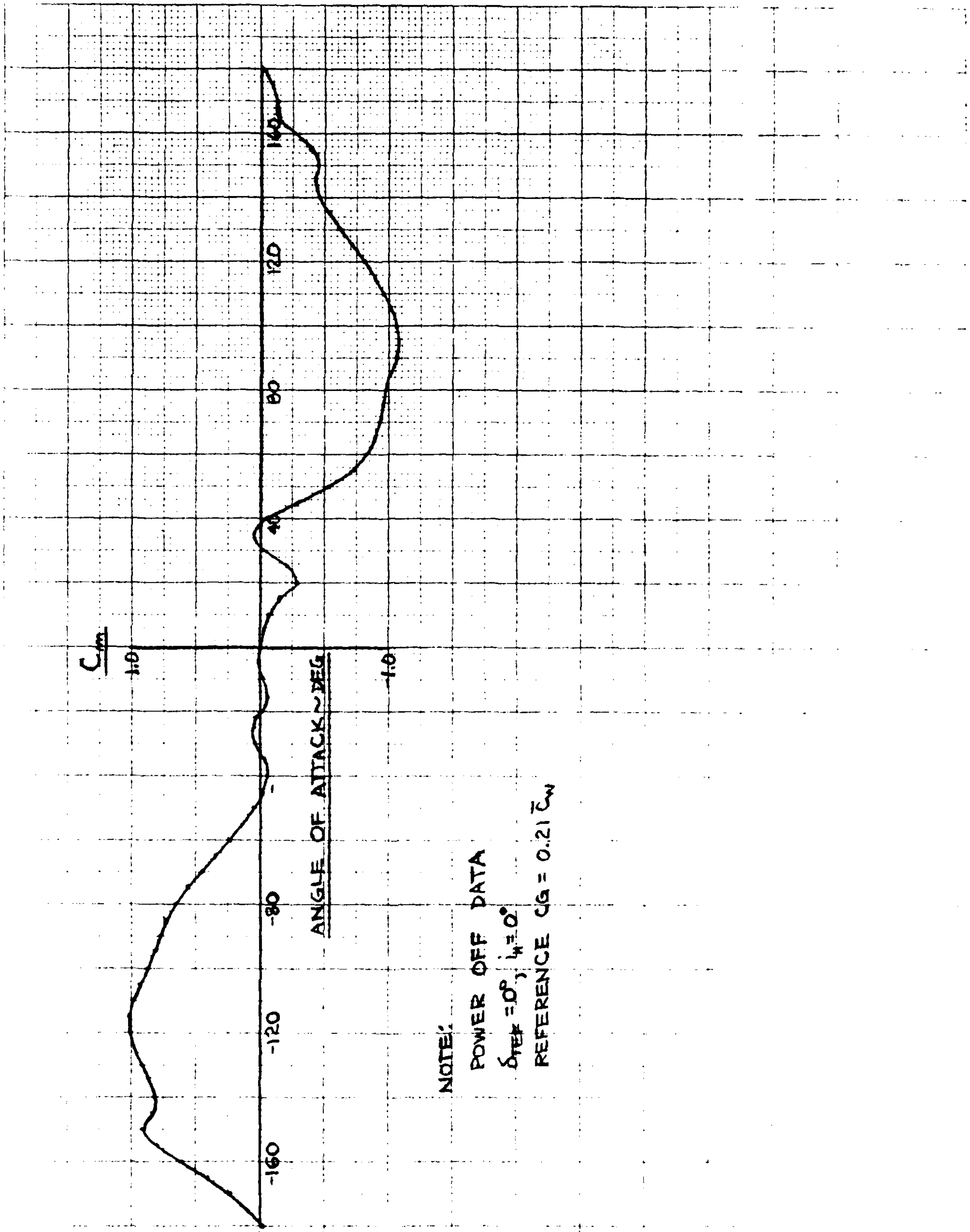


Figure B.1.2 (Cont.) - Tandem Fan High Angle of Attack (to ± 180 deg) Power Off Longitudinal Aerodynamics Characteristics

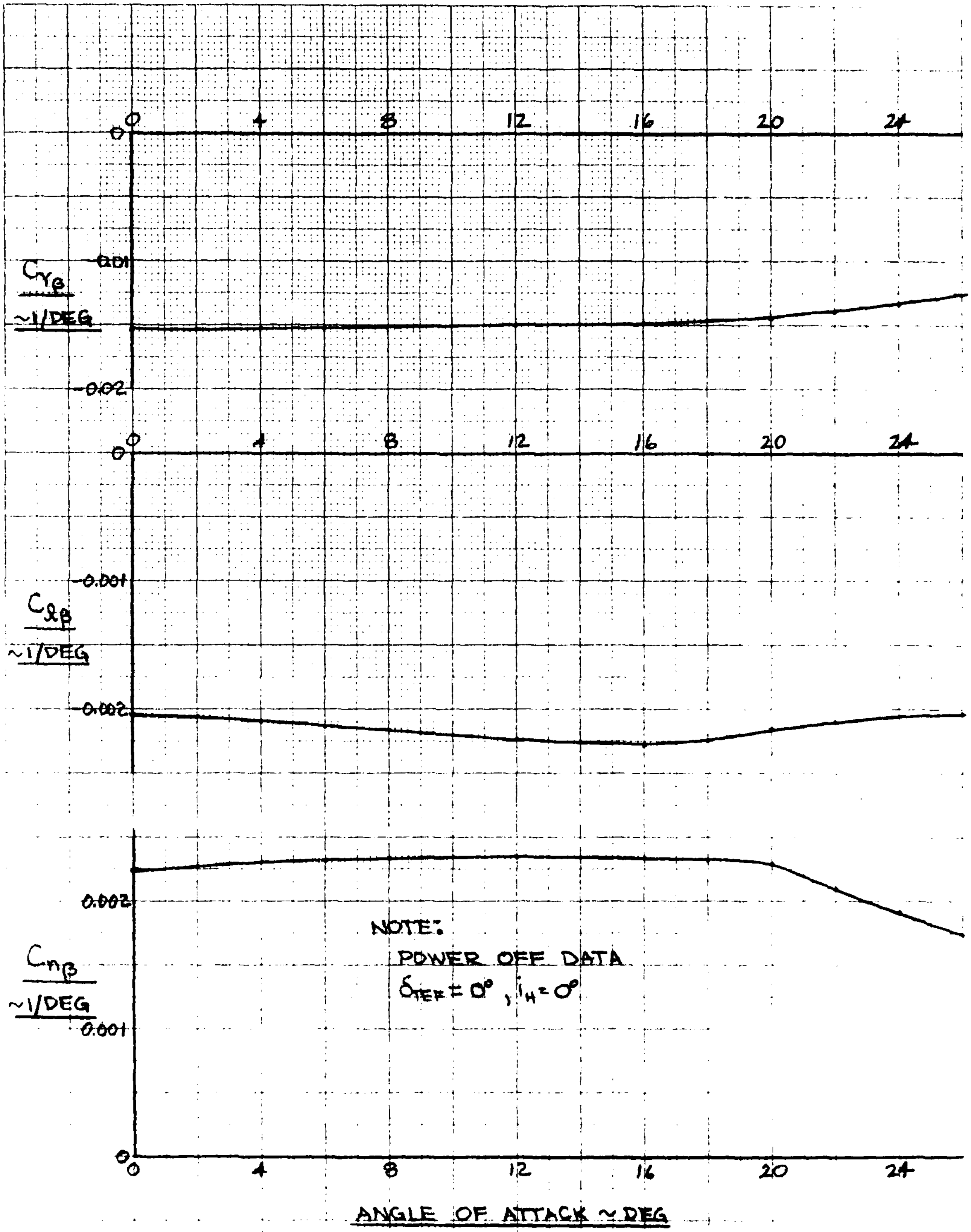


Figure B.1.3 - Tandem Fan Low Angle of Attack ($0 \leq \alpha \leq 30$ deg) Power Off Static Lateral Directional Derivatives

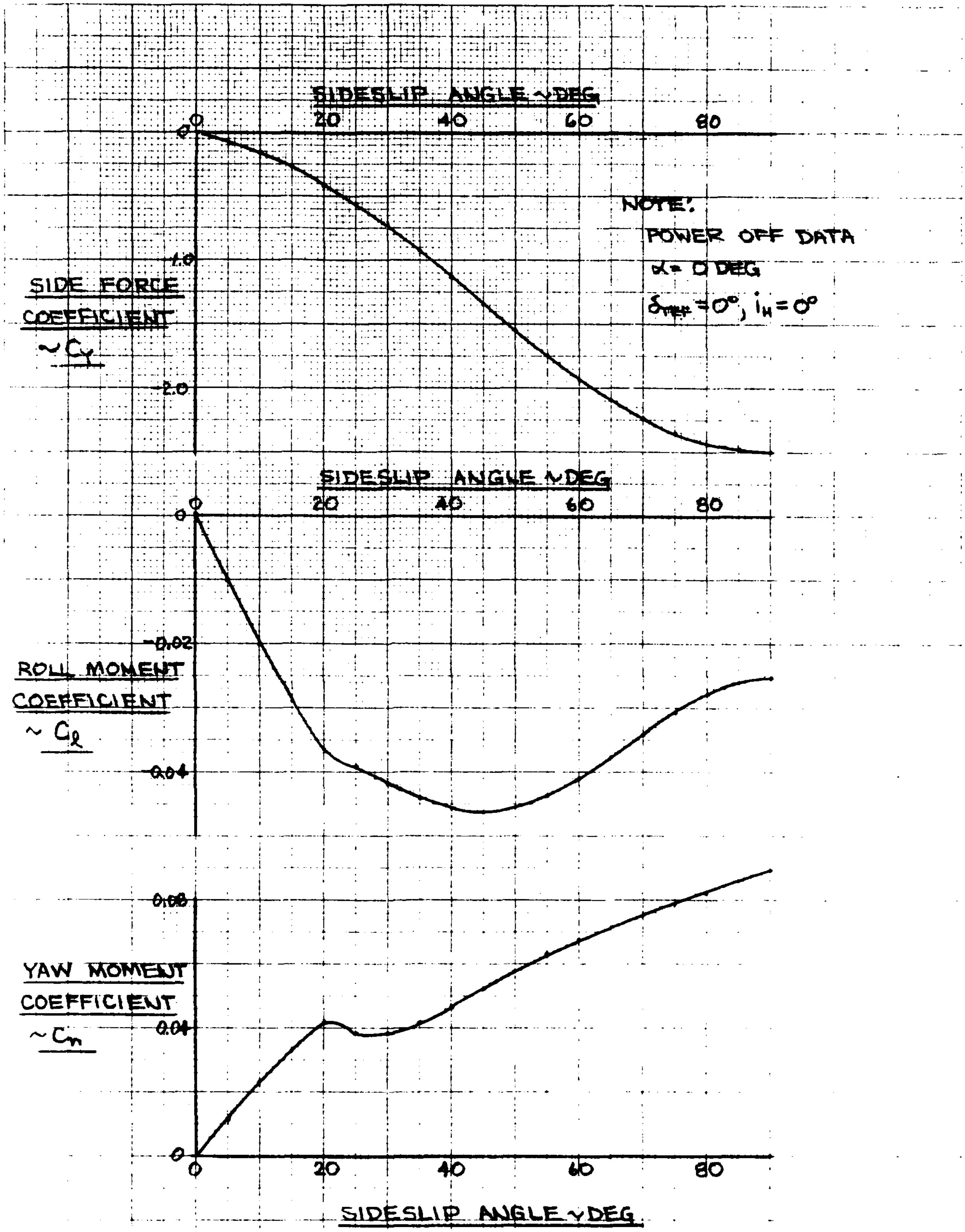


Figure B.1.4 - Tandem Fan Power Off Lateral Directional Aerodynamic Characteristics at Large Sideslip Angles (0 to 90 deg)

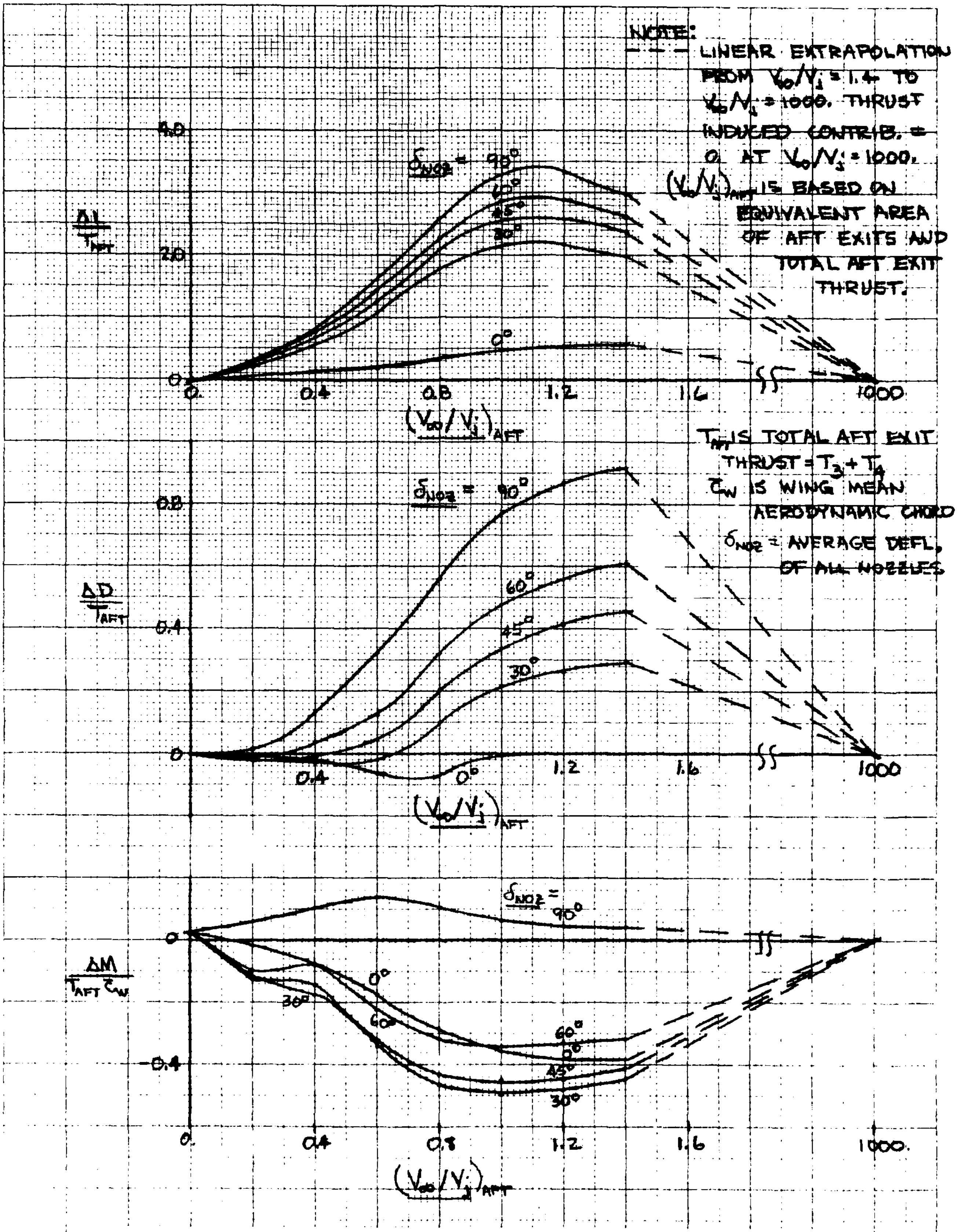
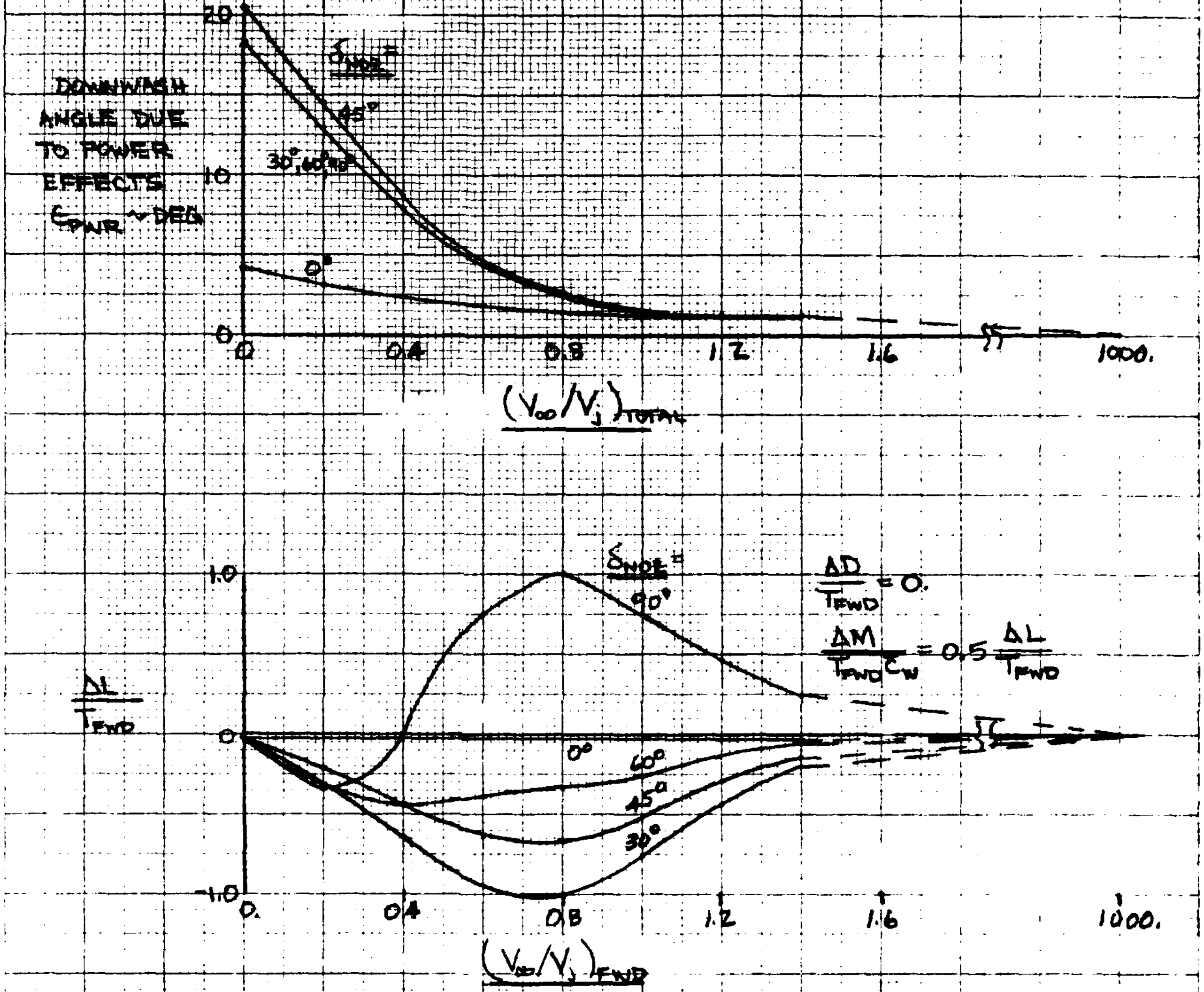


Figure B.1.5 - Tandem Fan Thrust - Induced Aerodynamic Characteristics



NOTE:

— — — LINEAR EXTRAPOLATION FROM $V_\infty/V_j = 1.4$ TO $V_\infty/V_j = 1000.$
THRUST INDUCED CONTRIBUTIONS = 0. AT $V_\infty/V_j = 1000.$

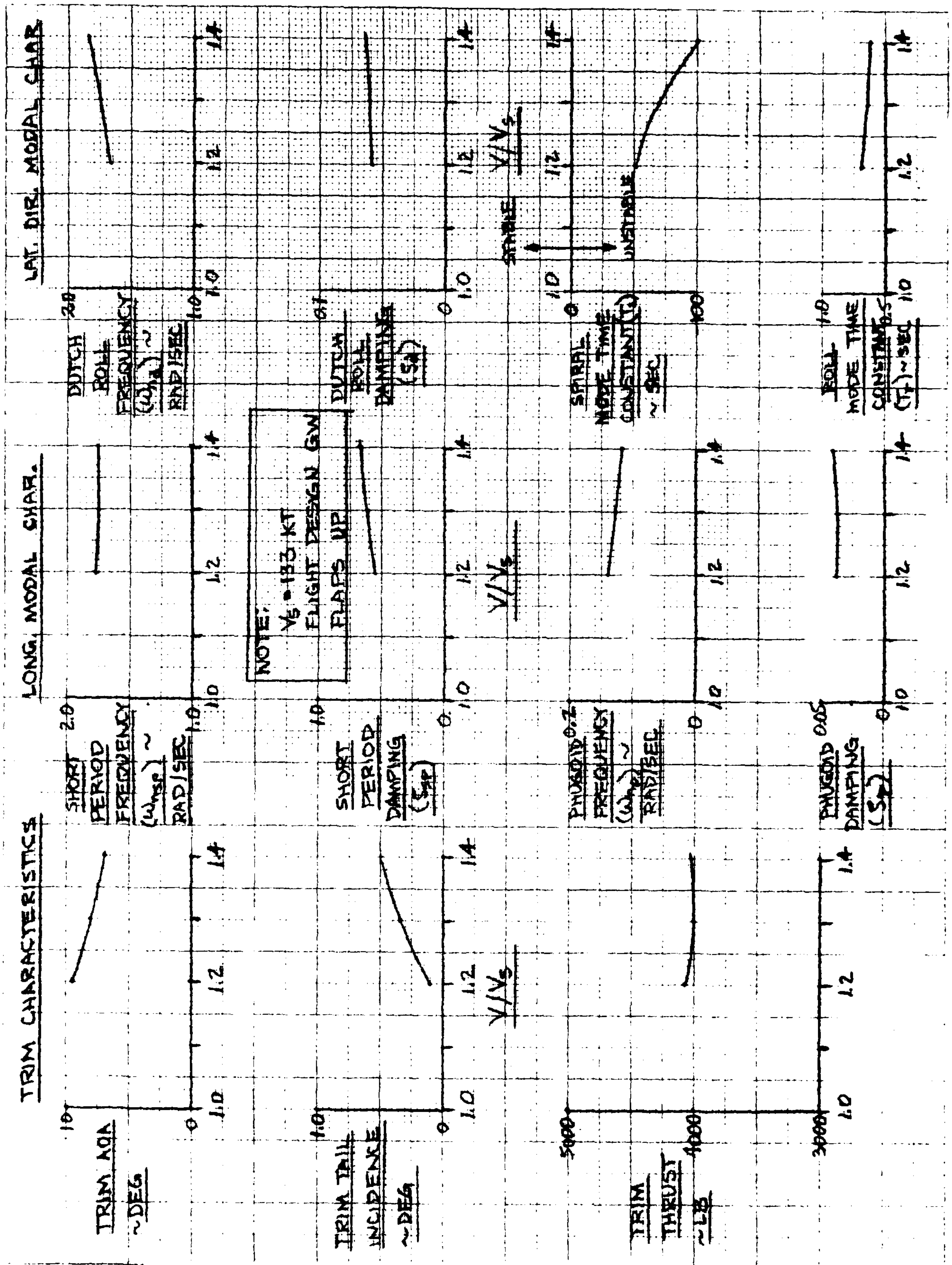
$(V_\infty/V_j)_{TOTAL}$ BASED ON TOTAL THRUST AND TOTAL EQUIVALENT NOZZLE EXIT AREA

$(V_\infty/V_j)_{FWD}$ BASED ON TOTAL FORWARD EXIT THRUST AND EQUIVALENT FORWARD NOZZLE EXIT AREA

T_{FWD} = TOTAL FORWARD EXIT THRUST = $T_1 + T_2$

δ_{NOZ} = AVERAGE DEFL. OF ALL NOZZLES

Figure B.1.5 (Cont.) - Tandem Fan Thrust - Induced Aerodynamic Characteristics



46 1470

Figure B.1.6 - Tandem Fan Cruise Trim Summary

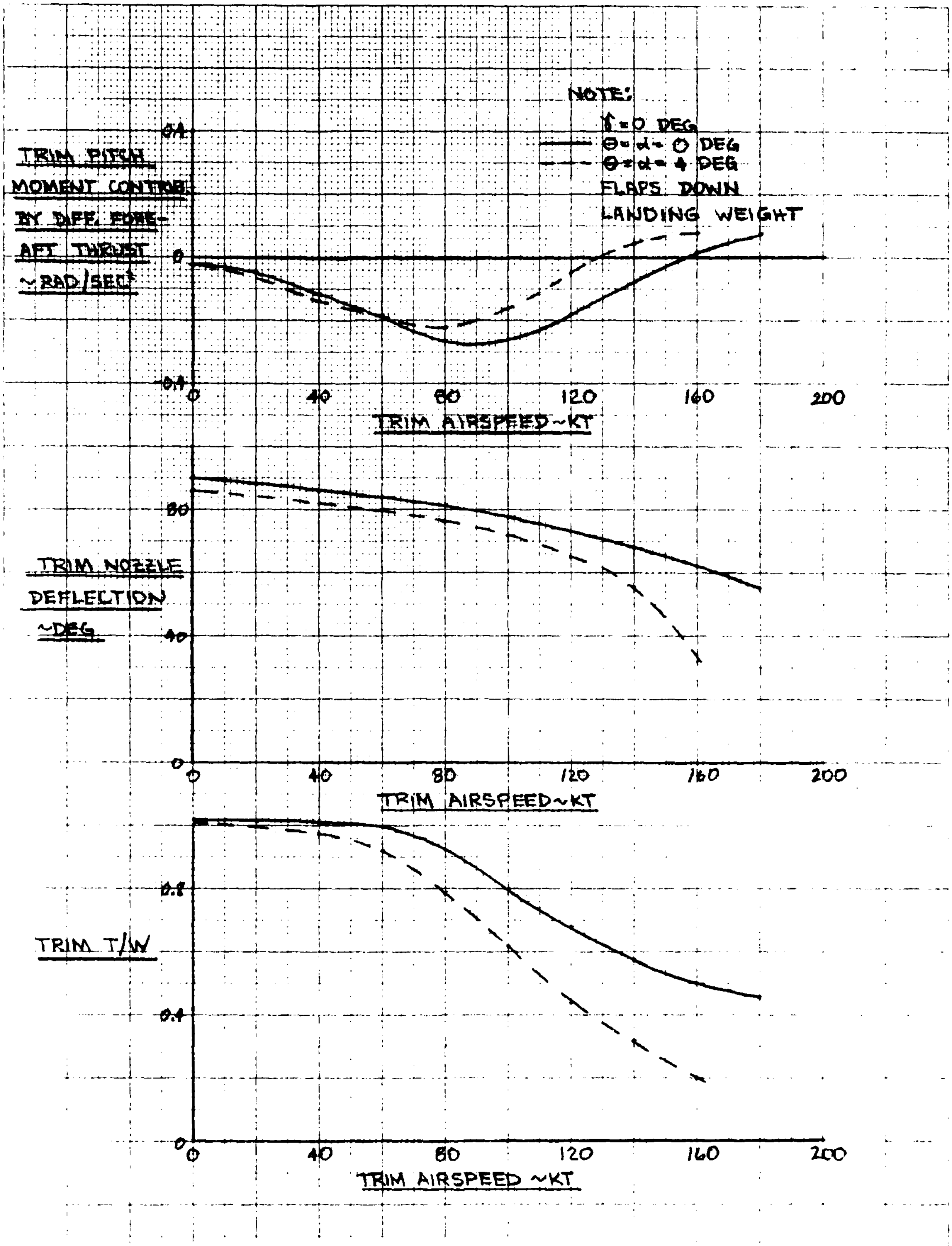


Figure B.1.7 - Tandem Fan Forward Flight Trim Summary

1. In Table B.1.1, the quantities pitch trim moment and roll trim moment applied by the propulsion system, have different interpretations in the various flight regimes. In hover and forward flight, differential fore-aft thrust for pitch and differential right-left thrust for roll are the primary means of trimming pitch and roll moments; in cruise flight these moments are related to trim thrust and must be trimmed by the aerodynamic control surfaces.

2. One pound of ΔT_{PITCH} or ΔT_{ROLL} (Tables B.1.2 and B.1.3) is produced by one pound thrust increases or decreases, as appropriate, at each of the four nozzles. For example, one pound of positive ΔT_{PITCH} is generated by one pound thrust increases at each forward nozzle and simultaneous one pound thrust decreases at each aft nozzle. With the airplane hovering in a 35 kt headwind, this one pound of ΔT_{PITCH} will produce 0.00047 rad/sec^2 (= $M_{\Delta T_{PITCH}}$) of pitch acceleration. Similarly, one pound of positive ΔT_{ROLL} is generated by one pound thrust increases at each left side nozzle and one pound thrust decreases at each right side nozzle. In the same 35 kt headwind condition this one pound of ΔT_{ROLL} will produce 0.00058 rad/sec^2 (= $L_{\Delta T_{ROLL}}$) of roll acceleration.

3. One pound of positive ΔT (Table B.1.2) corresponds to a one pound thrust increase at each of the four nozzles; i.e., ΔT is a per fan quantity and aircraft thrust increases or decreases four pounds for each pound of ΔT.

4. One degree of positive yaw thrust deflection (δ_{YAW}) (Tables B.1.1 and B.1.3) is produced by one degree increases in each of the left side nozzle angles and simultaneous one degree decreases in each of the right side nozzle angles. This one degree of positive δ_{YAW} generates -1.662 (= $N_{\delta_{YAW}}$)/57.3 = -0.029 rad/sec^2 yaw acceleration when the airplane is hovered in a 35 kt headwind.

Figure B.1.6 summarizes the cruise flight trim and modal characteristics of the Tandem Fan airplane while figure B.1.7 summarizes forward flight trim characteristics of the airplane.

B.2 Tilt Nacelle Airplane Data

B.2.1 Tilt Nacelle Power Off Aerodynamics Data

Figures B.2.1 through B.2.4 summarize the power off aerodynamics of the Tilt Nacelle airplane. The horizontal tail trailing edge flap (δ_{TEF_H}) or elevator deflection is varied to trim the airplane in aerodynamic flight and geared to reaction control system (RCS) pitch control in the forward and hover flight regimes. The wing trailing edge flap (δ_{TEF_W}) is deflected 30 deg to establish the flaps down configuration of the airplane.

B.2.2 Tilt Nacelle Thrust-Induced Effects

The Tilt Nacelle thrust induced effects model is based on data in reference (B-f). The model calculations are as follows:

$$\Delta L_{TI} = \bar{q}\, S_W (\Delta C_L)_{PWR}$$

$$\Delta D_{TI} = \bar{q}\, S_W (\Delta C_D)_{PWR}$$

$$\Delta M_{TI} = 0.$$

$$\left(\frac{\partial \epsilon}{\partial \alpha}\right)_{TI} = \left(\frac{\partial \epsilon}{\partial \alpha}\right)_{PWR} SF$$

$$SF = \begin{cases} 1.0 & SF \geq 1.0 \\ 1.5 - 0.03333\left|\alpha_H\right| & 0. < SF < 1.0 \\ 0.0 & SF \leq 0. \end{cases}$$

$$(\Delta C_L)_{PWR} = f\left[\delta_{NOZ}, (V_\infty/V_j)\right]$$

$$(\Delta C_D)_{PWR} = f\left[\delta_{NOZ}, (V_\infty/V_j)\right]$$

$$\left(\frac{\partial \epsilon}{\partial \alpha}\right)_{PWR} = f\left[\delta_{NOZ}, (V_\infty/V_j)\right]$$

$$(V_\infty/V_j) = \sqrt{\frac{2\bar{q}\,(2\pi) r_e^2}{T_R + T_L}}$$

where

ΔL_{TI}, ΔD_{TI}, and ΔM_{TI} are the thrust-induced lift, drag, and pitching moment in the stability axis system. ΔL_{TI} and ΔD_{TI} have units of lb; ΔM_{TI} has units of ft lb.

$\left(\frac{\partial\epsilon}{\partial\alpha}\right)_{TI}$ is the thrust-induced downwash gradient

α_H is the tail angle of attack, deg

δ_{NOZ} is the average nozzle deflection, deg

T_R is the thrust of the right fan, lb

T_L is the thrust of the left fan, lb

$\bar{q}$ is dynamic pressure, lb/ft^2

r_e is the equivalent radius of one of the nacelle exit areas, ft

S_W is reference wing area, ft^2

$\bar{c}_W$ is the wing mean aerodynamic chord, ft

$(\Delta C_L)_{PWR}$, $(\Delta C_D)_{PWR}$, and $\left(\frac{\partial\epsilon}{\partial\alpha}\right)_{PWR}$ are plotted on figure B.2.5 as functions of δ_{NOZ} and (V_∞/V_j).

B.2.3 Tilt Nacelle Trim Summary

Tables B.2.1 through B.2.3 and figures B.2.6 and B.2.7 constitute the Tilt Nacelle trim summary. The following notes clarify certain table entries which are configuration specific:

1. Since the pitch RCS is continuous bleed and is oriented to provide an upward force on the airplane, the Z-axis component of the RCS is included in the "total thrust" entry in Table B.2.1.

2. The trim roll moment applied by the propulsion system (Table B.2.1) is generated by differential right-left thrust balance.

3. One degree of positive yaw thrust deflection (δ_{YAW}) (Tables B.2.1 and B.2.3) is produced by one degree increase in left nacelle tilt angle and a simultaneous one degree decrease in right nacelle tilt angle. This one degree of positive δ_{YAW} generates -1.603 (= $N_{\delta_{YAW}}$)/57.3 = -0.0280 rad/sec^2 yaw acceleration when the aircraft is hovered in a 35 kt headwind.

4. If the trim pitch moment applied by the RCS (Table B.2.1) is in a nose down (negative) direction, then one pound of RCS pitch force (RCS_{PITCH}) (Table B.2.2) is produced by a one pound increase or decrease in forward RCS jet thrust for nose up or nose down control, respectively, from trim. Conversely if the trim pitch moment is in a nose up (positive) direction, then one pound of RCS_{PITCH} is produced by a one pound increase or decrease in rear RCS jet thrust for nose down or nose up control, respectively, from trim. The RCS pitch control of the Tilt Nacelle airplane is therefore height coupled in that the Z force on the airplane changes as pitch control moments are changed.

5. One pound of positive ΔT_{ROLL} (Table B.2.3) is produced by a one pound increase in left fan thrust and a simultaneous one pound decrease in right fan thrust.

Figure B.2.6 summarizes the cruise flight trim and modal characteristics of the Tilt Nacelle airplane while figure B.2.7 summarizes forward flight trim characteristics of the airplane.

Table B.2.1 Trim and Modal Characteristics of Tilt Nacelle Airplane

PARAMETER / FLIGHT CONDITION	HOVER HEADWIND FLAPS DOWN	HOVER 45 DEG. CROSSWIND FLAPS DOWN	HOVER 90 DEG CROSSWIND FLAPS DOWN	FWD. FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT
- TRIM CHARACTERISTICS							
True Airspeed, kt	35.0	35.0	35.0	40.0	40.0	80.0	80.0
Pitch Angle, deg	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bank Angle, deg	0.0	-6.58	-11.0	0.0	0.0	0.0	0.0
Angle of Attack, deg	0.0	-6.54	-90.01	0.0	0.0	0.0	0.0
Sideslip Angle, deg	0.0	-44.63	-79.00	0.0	0.0	0.0	0.0
Total Thrust, lb	30131	30971	33093	29558	40378	25415	35466
Nozzle Deflection, deg	82.61	83.89	87.01	81.26	82.00	70.27	71.97
Trim Pitch Moment Appl. by RCS, ft-lb	-12314	-8774	126.5	-12434	-20231	-11370	-20632
Trim Roll Moment Appl. by Prop. Sys., ft-lb	0.0	-13642	-21733	0.0	0.0	0.0	0.0
Yaw Thrust Deflection, deg	0.0	0.75	1.58	0.0	0.0	0.0	0.0
Tail Incidence, deg	4.92	5.00	5.00	4.64	4.80	2.49	2.74
Elevator Deflection, deg	3.65	2.52	-0.10	3.76	4.47	3.99	5.19

Table B.2.1 Trim and Modal Characteristics of Tilt Nacelle Airplane (Continued)

PARAMETER \ FLIGHT CONDITION	HOVER HEADWIND FLAPS DOWN	HOVER 45 DEG. CROSSWIND FLAPS DOWN	HOVER 90 DEG CROSSWIND FLAPS DOWN	FWD. FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT
- MODAL CHARACTERISTICS*							
Longitudinal	[0.0390, 0.273; -0.141, 0.276] (-0.528) (-0.181)	[0.0626, 0.254; -0.239, 0.262] (-0.423) (-0.165)	[0.224, 0.439; -0.454, 0.493] (-0.534) (-0.0701)	[-0.214, 0.104; 0.900, 0.238] (-0.487) (0.124)	[0.0553, 0.313; -0.174, 0.317] (-0.681) (-0.167)	[-0.0331, 0.0252; 0.796, 0.0416] (-0.526) (-0.874)	(-0.135) (-0.486) (-0.797) (0.0783)
Lateral	[0.198, 0.508; -0.364, 0.546] (-0.701) (-0.0300)	[0.186, 0.493; -0.353, 0.527] (-0.6[illegible]8) (-0.0372)	[0.214, 0.509; -0.387, 0.552] (-0.675) (-0.0567)	[0.175, 0.542; -0.307, 0.569] (-0.688) (-0.0285)	[0.206, 0.566; -0.342, 0.602] (-0.728) (-0.0342)	[0.0631, 0.675; -0.0931, 0.678] (-0.739) (-0.0138)	[0.100, 0.660; -0.150, 0.668] (-0.757) (-0.0261)

*$[-\zeta\omega_n, \omega_n\sqrt{1-\zeta^2}; \zeta, \omega_n]$ indicates complex root pair located at $s = -\zeta\omega_n \pm j\omega_n\sqrt{1-\zeta^2}$ with natural frequency of ω_n rad/sec and damping ratio of ζ

(λ) indicates real root located at $s = \lambda$

Table B.2.1 Trim and Modal Characteristics of Tilt Nacelle Airplane (Continued)

DERIVATIVE \ FLIGHT CONDITION	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT.	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLT. 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLT. 1.4 V_s FLAPS UP FLT. DES. WGT.
- TRIM CHARACTERISTICS						
True Airspeed, kt	120.0	120.0	120.0	160.0	200.0	191.8
Pitch Angle, deg	0.0	0.0	4.0	4.0	3.48	6.97
Bank Angle, deg	0.0	0.0	0.0	0.0	0.0	0.0
Angle of Attack, deg	0.0	0.0	4.0	4.0	3.48	6.97
Sideslip Angle, deg	0.0	0.0	0.0	0.0	0.0	0.0
Total Thrust, lb	23186	32146	17855	16173	7617	5961
Nozzle Deflection, deg	57.72	61.48	47.85	21.03	0.0	0.0
Trim Pitch Moment Appl. by RCS, ft-lb	-12483	-19792	-9638	-7978	-53.119	-41.569
Trim Roll Moment Appl. by Prop. Sys., ft-lb	0.0	0.0	0.0	0.0	0.0	0.0
Yaw Thrust Deflection, deg	0.0	0.0	0.0	0.0	0.0	0.0
Tail Incidence, deg	1.40	1.62	1.09	0.48	0.0	0.0
Elevator Deflection, deg	4.80	5.49	4.82	4.41	5.16	-0.54

Table B.2.1 Trim and Modal Characteristics of Tilt Nacelle Airplane (Concluded)

DERIVATIVE \ FLIGHT CONDITION	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 1.4 V_s FLAPS UP FLT. DES. WGT
- MODAL CHARACTERISTICS						
Longitudinal	(-1.377)	(-1.406)	[-0.0298, 0.0271; 0.741, 0.0403]	[-0.0374, 0.0193; 0.888, 0.0421]	[-0.0163, 0.0754; 0.212, 0.0771]	[-0.00895, 0.101; 0.0880, 0.102]
	(-0.646) (-0.0999)	(-0.448) (-0.0805)	(-1.249)	(-1.666)	[-1.783, 0.100; 0.998, 1.786]	[-1.706, 0.945; 0.875, 1.950]
	(0.0238)	(0.0223)	(-0.954)	(-1.268)		
Lateral	[-0.00717, 0.907; 0.00791, 0.907]	[0.0209, 0.866; -0.0241, 0.867]	[-0.0143, 0.963; 0.0148, 0.963]	[-0.0647, -1.239; 0.0522, 1.240]	[-0.0996, 1.583; 0.0628, 1.586]	[-0.0921, 1.563; 0.0588, 1.566]
	(-0.881)	(-0.853)	(-0.881)	(-1.058)	(-1.243)	(-1.172)
	(-0.00252)	(-0.0102)	(0.0183)	(0.0211)	(0.0211)	(0.0267)

Table B.2.2 Longitudinal Stability Derivatives Of Tilt Nacelle Airplane

FLIGHT CONDITION / DERIVATIVE	HOVER 35 KT HEADWIND FLAPS DOWN	HOVER 35 KT 45 DEG CROSSWIND FLAPS DOWN	HOVER 35 KT 90 DEG CROSSWIND FLAPS DOWN	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT
- X - DERIVATIVES							
X_u - ft/sec^2/ft/sec	-0.0822	-0.0761	-0.0449	-0.0728	-0.0764	-0.0711	-0.0640
X_w - ft/sec^2/ft/sec	0.00676	-0.00707	0.00834	0.00761	0.00631	0.0106	0.0105
X_q - ft/sec^2/rad/sec	-0.452	-0.418	-0.518	-0.441	-0.456	-0.382	-0.392
$X_{\delta e}$ - ft/sec^2/rad	-0.556	-0.381	0.0	-0.0692	-0.0531	-0.168	-0.136
$X_{RSPITCH}$ - ft/sec^2/lb	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$X_{\delta NOZ}$ - ft/sec^2/rad	-28.81	-29.68	-31.78	-28.29	-28.93	-23.88	-25.24
$X_{\Delta T}$ - ft/sec^2/lb	0.00009	0.00009	0.00010	0.00005	0.00006	0.00025	0.00011
- Z - DERIVATIVES							
Z_u - ft/sec^2/ft/sec	-0.0810	-0.0456	-0.00043	-0.0815	-0.0706	-0.0939	-0.0831
Z_w - ft/sec^2/ft/sec	-0.0202	-0.150	-0.0701	-0.227	-0.176	-0.422	-0.321
Z_q - ft/sec^2/rad/sec	-0.616	-0.281	-0.0761	-0.720	-0.539	-1.528	-1.144
$Z_{\delta e}$ - ft/sec^2/rad	-1.082	-0.568	0.0	-1.421	-1.058	-5.932	-4.407
$Z_{RSPITCH}$ - ft/sec^2/lb	0.00099	0.00099	0.00099	0.00099	0.00074	0.00099	0.00074
$Z_{\delta NOZ}$ - ft/sec^2/rad	-4.124	-3.254	-1.061	-4.281	-4.548	-11.07	-12.77
$Z_{\Delta T}$ - ft/sec^2/lb	-0.00210	-0.00211	-0.00212	-0.00214	-0.00157	-0.00217	-0.00160

Table B.2.2 Longitudinal Stability Derivatives of Tilt Nacelle Airplane (Continued)

DERIVATIVE / FLIGHT CONDITION	HOVER 35 KT HEADWIND FLAPS DOWN	HOVER 35 KT 45 DEG CROSSWIND FLAPS DOWN	HOVER 35 KT 90 DEG CROSSWIND FLAPS DOWN	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT
- M - DERIVATIVES							
M_u - rad/sec^2/ft/sec	0.00115	0.00084	0.00411	-0.00052	0.00202	-0.00014	-0.00063
M_w - rad/sec^2/ft/sec	0.00006	-0.00052	0.00001	-0.00013	0.0	-0.00090	-0.00089
M_{q_b} - rad/sec^2/rad/sec	-0.348	-0.236	-0.0408	-0.398	-0.392	-0.790	-0.775
M_{δ_e} - rad/sec^2/rad	-0.246	-0.127	0.0	-0.324	-0.317	-1.359	-1.327
$M_{RCS_{PITCH}}$ - rad/sec^2/lb	0.00032	0.00032	0.00032	0.00032	0.00031	0.00032	0.00031
$M_{\delta_{NOZ}}$ - rad/sec^2/rad	-0.0964	0.00344	0.0445	0.0351	-0.188	0.131	-0.679
$M_{\delta T}$ - rad/sec^2/lb	0.00001	0.0	0.0	0.00001	0.00001	0.00001	0.00002

Table B.2.2 Longitudinal Stability Derivatives of Tilt Nacelle Airplane (Continued)

DERIVATIVE \ FLIGHT CONDITION	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT.	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLT. 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLT. 1.4 V_s FLAPS UP FLT. DES. WGT.
- X - DERIVATIVES						
X_u - $ft/sec^2/ft/sec$	-0.0734	-0.0545	-0.0588	-0.0699	-0.0282	-0.0148
X_w - $ft/sec^2/ft/sec$	0.0111	0.00909	0.0593	0.0799	0.0881	0.124
X_q - $ft/sec^2/rad/sec$	-0.339	-0.345	-0.178	-0.0538	0.0377	-0.248
X_{δ_e} - $ft/sec^2/rad$	-0.252	-0.206	0.0874	0.304	-4.301	3.037
$X_{RCS_{PITCH}}$ - $ft/sec^2/lb$	0.0	0.0	0.0	0.0	0.0	0.0
$X_{\delta_{NOZ}}$ - $ft/sec^2/rad$	-19.41	-21.36	-13.99	-6.211	0.0479	0.0603
$X_{\Delta T}$ - $ft/sec^2/lb$	0.00046	0.00020	0.00070	0.00114	0.00128	0.00110
- Z - DERIVATIVES						
Z_u - $ft/sec^2/ft/sec$	-0.0835	-0.0706	-0.0987	-0.112	-0.127	-0.0975
Z_w - $ft/sec^2/ft/sec$	-0.607	-0.460	-0.626	-0.830	-0.988	-0.805
Z_q - $ft/sec^2/rad/sec$	-2.208	-1.671	-2.365	-3.186	-3.706	-3.075
Z_{δ_e} - $ft/sec^2/rad$	-15.96	-10.13	-13.00	-23.27	-37.04	-26.62
$Z_{RCS_{PITCH}}$ - $ft/sec^2/lb$	0.00099	0.00074	0.00099	0.00099	0.00099	0.00083
$Z_{\delta_{NOZ}}$ - $ft/sec^2/rad$	-18.63	-17.11	-15.15	-18.96	-10.54	-7.26
$Z_{\Delta T}$ - $ft/sec^2/lb$	-0.00219	-0.00166	-0.00214	-0.00125	-0.00019	-0.00020

Table B.2.2 Longitudinal Stability Derivatives of Tilt Nacelle Airplane (Concluded)

DERIVATIVE \ FLIGHT CONDITION	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT.	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLT. 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLT. 1.4 V_s FLAPS UP FLT. DES. WGT.
- M - DERIVATIVES						
M_u - rad/sec^2/ft/sec	-0.00024	-0.00016	-0.00020	-0.00020	0.00017	0.00074
M_w - rad/sec^2/ft/sec	-0.00095	-0.00055	-0.00198	-0.00265	-0.00339	-0.00654
M_q - rad/sec^2/rad/sec	-1.157	-1.138	-1.276	-1.707	-2.094	-2.115
M_{δ_e} - rad/sec^2/rad	-3.129	-3.060	-3.051	-5.474	-8.053	-7.861
$M_{RCS_{PITCH}}$ - rad/sec^2/lb	0.00032	0.00031	0.00032	0.00032	0.00032	0.00032
$M_{\delta_{NOZ}}$ - rad/sec^2/rad	0.268	-0.328	0.221	0.334	0.207	0.153
$M_{\delta T}$ - rad/sec^2/lb	0.00002	0.00002	0.00002	0.00002	0.0	0.00001

Table B.2.3 Lateral Stability Derivatives of Tilt Nacelle Airplane

DERIVATIVE \ FLIGHT CONDITION	HOVER 35 KT HEADWIND FLAPS DOWN	HOVER 35 KT 45 DEG CROSSWIND FLAPS DOWN	HOVER 35 KT 90 DEG CROSSWIND FLAPS DOWN	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT
- Y - DERIVATIVES							
Y_v - $ft/sec^2/ft/sec$	-0.0649	-0.129	-0.164	-0.0663	-0.0615	-0.0812	-0.0710
Y_p - $ft/sec^2/rad/sec$	0.404	0.427	0.439	0.383	0.417	0.208	0.276
Y_r - $ft/sec^2/rad/sec$	0.246	0.210	0.227	0.281	0.224	0.551	0.441
Y_{δ_A} - $ft/sec^2/rad$	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$Y_{DT_{ROLL}}$ - $ft/sec^2/lb$	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Y_{δ_R} - $ft/sec^2/rad$	0.233	0.0604	0.0	0.304	0.227	1.215	0.907
$Y_{\delta_{YAW}}$ - $ft/sec^2/rad$	0.0	0.00437	0.00164	0.0	0.0	0.0	0.0
- L - DERIVATIVES							
L_v - $rad/sec^2/ft/sec$	-0.00657	-0.00594	-0.00663	-0.00643	-0.00780	-0.00596	-0.00693
L_p - $rad/sec^2/rad/sec$	-0.234	-0.179	-0.0817	-0.261	-0.248	-0.479	-0.445
L_r - $rad/sec^2/rad/sec$	0.0468	-0.00066	0.0217	0.0534	0.0478	0.107	0.0954
L_{δ_A} - $rad/sec^2/rad$	-0.0985	-0.0569	0.0	-0.129	-0.117	-0.515	-0.466
$L_{DT_{ROLL}}$ - $rad/sec^2/lb$	0.00023	0.00023	0.00022	0.00023	0.00020	0.00022	0.00020
L_{δ_R} - $rad/sec^2/rad$	0.0261	0.00678	0.0	0.0341	0.0309	0.136	0.123
$L_{\delta_{YAW}}$ - $rad/sec^2/rad$	0.317	0.281	0.181	0.381	0.411	0.932	1.006

Table B.2.3 Lateral Stability Derivatives of Tilt Nacelle Airplane (Continued)

DERIVATIVE \ FLIGHT CONDITION	HOVER 35 KT HEADWIND FLAPS DOWN	HOVER 35 KT 45 DEG CROSSWIND FLAPS DOWN	HOVER 35 KT 90 DEG CROSSWIND FLAPS DOWN	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT
- N - DERIVATIVES							
N_v - rad/sec^2/ft/sec	0.00110	0.00075	0.00151	0.00124	0.00106	0.00252	0.00217
N_p - rad/sec^2/rad/sec	0.00249	0.0242	0.013	0.00281	0.00238	0.00570	0.00478
N_r - rad/sec^2/rad/sec	-0.0373	-0.0366	-0.0603	-0.0408	-0.0423	-0.0693	-0.0691
N_{δ_A} - rad/sec^2/rad	0.00116	0.00220	0.0	0.00152	0.00144	0.00607	0.00574
$N_{\delta T_{ROLL}}$ - rad/sec^2/lb	0.0	0.0	0.0	0.0	0.0	0.00002	0.00001
N_{δ_R} - rad/sec^2/rad	-0.0299	-0.00973	0.0	-0.0391	-0.0370	-0.156	-0.148
$N_{\delta_{YAW}}$ - rad/sec^2/rad	-1.603	-1.641	-1.741	-1.568	-2.038	-1.287	-1.717

Table B.2.3 Lateral Stability Derivatives of Tilt Nacelle Airplane (Continued)

DERIVATIVE \ FLIGHT CONDITION	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT.	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLT. 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLT. 1.4 V_s FLAPS UP FLT DES WGT
- Y - DERIVATIVES						
Y_v - ft/sec^2/ft/sec	-0.105	-0.0860	-0.0989	-0.124	-0.139	-0.110
Y_p - ft/sec^2/rad/sec	0.0505	0.143	-0.0522	-0.262	-0.445	-0.356
Y_r - ft/sec^2/rad/sec	0.817	0.647	0.809	1.063	1.143	0.898
Y_{δ_A} - ft/sec^2/rad	0.0	0.0	0.0	0.0	0.0	0.0
$Y_{\delta T_{ROLL}}$ - ft/sec^2/lb	0.0	0.0	0.0	0.0	0.0	0.0
Y_{δ_R} - ft/sec^2/rad	2.733	2.040	2.719	4.834	7.563	5.774
$Y_{\delta_{YAW}}$ - ft/sec^2/rad	0.0	0.0	0.0	0.0	0.0	0.0
- L - DERIVATIVES						
L_v - rad/sec^2/ft/sec	-0.00664	-0.00706	-0.00696	-0.00771	-0.00846	-0.00855
L_p - rad/sec^2/rad/sec	-0.699	-0.643	-0.697	-0.918	-1.136	-1.085
L_r - rad/sec^2/rad/sec	0.161	0.144	0.254	0.342	0.409	0.388
L_{δ_A} - rad/sec^2/rad	-1.158	-1.049	-1.247	-2.216	-3.445	-3.163
$L_{\delta T_{ROLL}}$ - rad/sec^2/lb	0.00020	0.00019	0.00018	0.00009	0.00001	0.00001
L_{δ_R} - rad/sec^2/rad	0.307	0.278	0.305	0.543	0.849	0.767
$L_{\delta_{YAW}}$ - rad/sec^2/rad	1.339	1.509	1.297	1.735	0.868	0.672

Table B.2.3 Lateral Stability Derivatives of Tilt Nacelle Airplane (Concluded)

DERIVATIVE \ FLIGHT CONDITION	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT.	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLT. 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLT. 1.4 V_s FLAPS UP FLT DES WGT
- N - DERIVATIVES						
N_v - rad/sec^2/ft/sec	0.00374	0.00334	0.00375	0.00503	0.00696	0.00667
N_p - rad/sec^2/rad/sec	0.00890	0.00765	-0.0444	-0.0576	-0.0582	-0.102
N_r - rad/sec^2/rad/sec	-0.0989	-0.0967	-0.0996	-0.131	-0.155	-0.138
N_{δ_A} - rad/sec^2/rad	0.0137	0.0129	-0.00807	-0.0143	-0.0144	-0.0954
$N_{\Delta T_{ROLL}}$ - rad/sec^2/lb	0.00004	0.00003	0.00005	0.00007	0.00007	0.00007
N_{δ_R} - rad/sec^2/rad	-0.352	-0.333	-0.350	-0.622	-0.974	-0.883
$N_{\delta_{YAW}}$ - rad/sec^2/rad	-1.089	-1.485	-0.739	-0.306	0.00271	0.00406

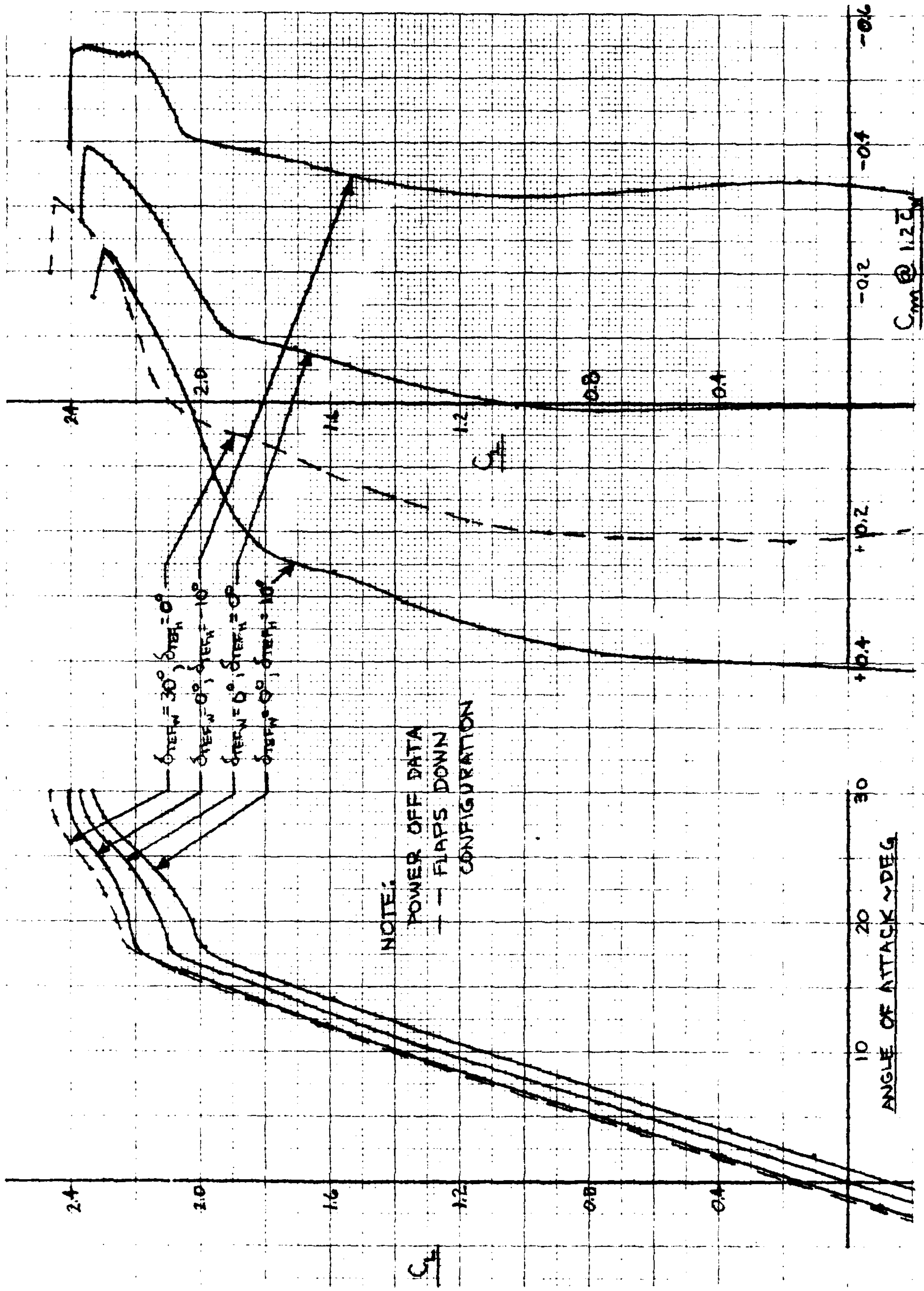


Figure B.2.1 - Tilt Nacelle Low Angle of Attack ($0 \leq \alpha \leq 30$ deg) Power Off Longitudinal Aerodynamic Characteristics

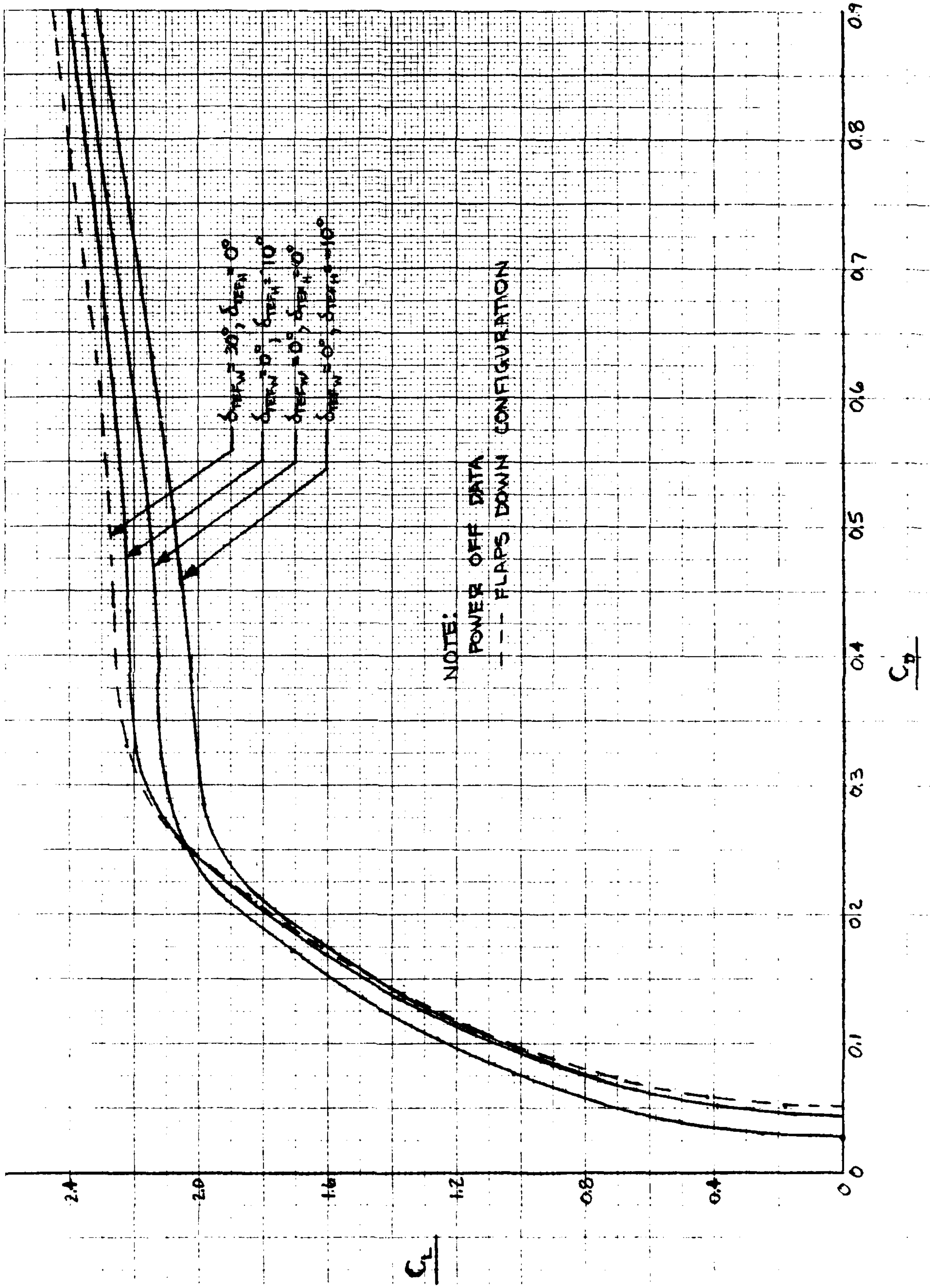


Figure B.2.1 (Cont.) - Tilt Nacelle Low Angle of Attack ($0 \leq \alpha \leq 30$ deg) Power Off Longitudinal Aerodynamic Cnaracteristics

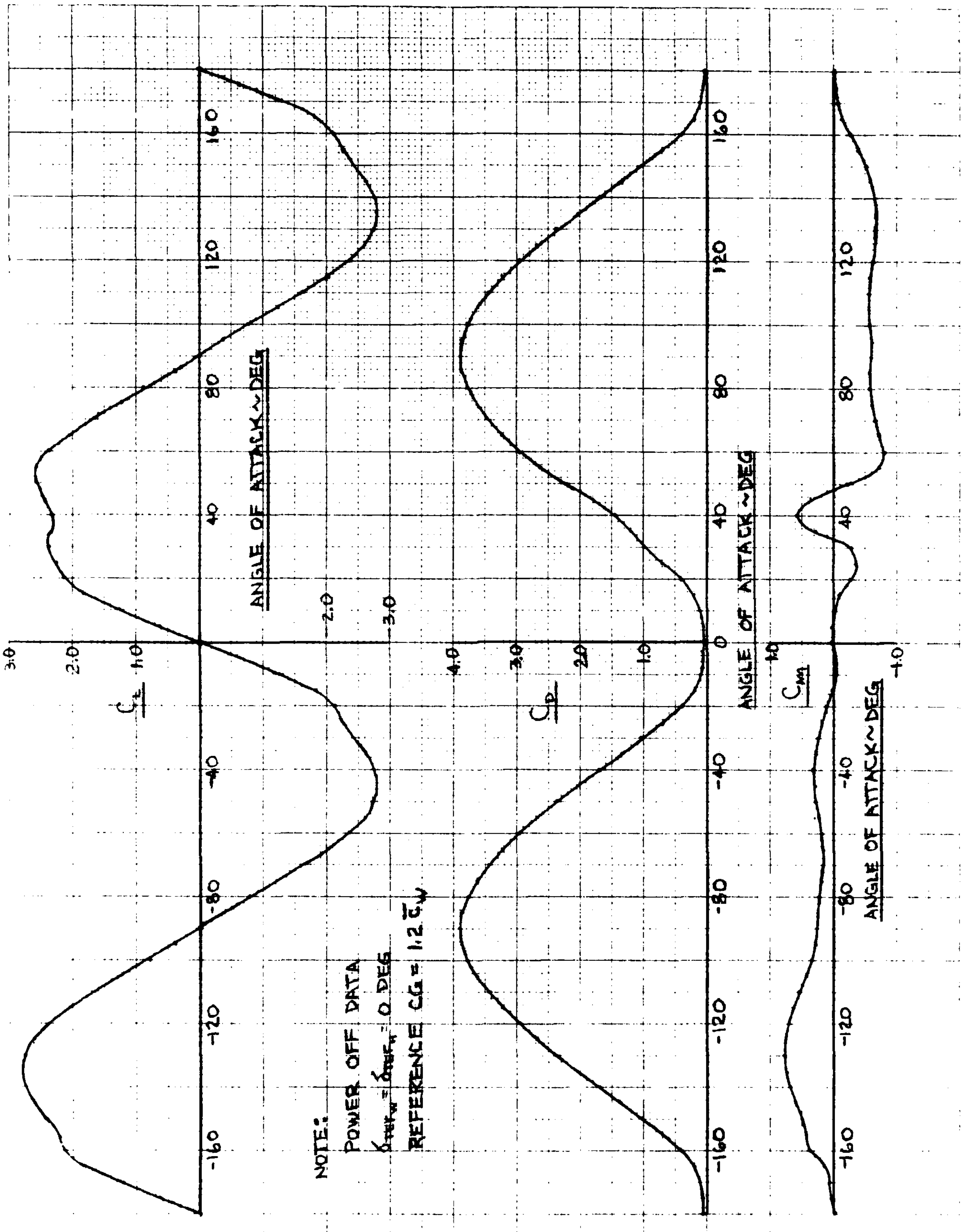


Figure B.2.2 - Tilt Nacelle High Angle of Attack (to ± 180 deg) Power Off Longitudinal Aerodynamic Characteristics

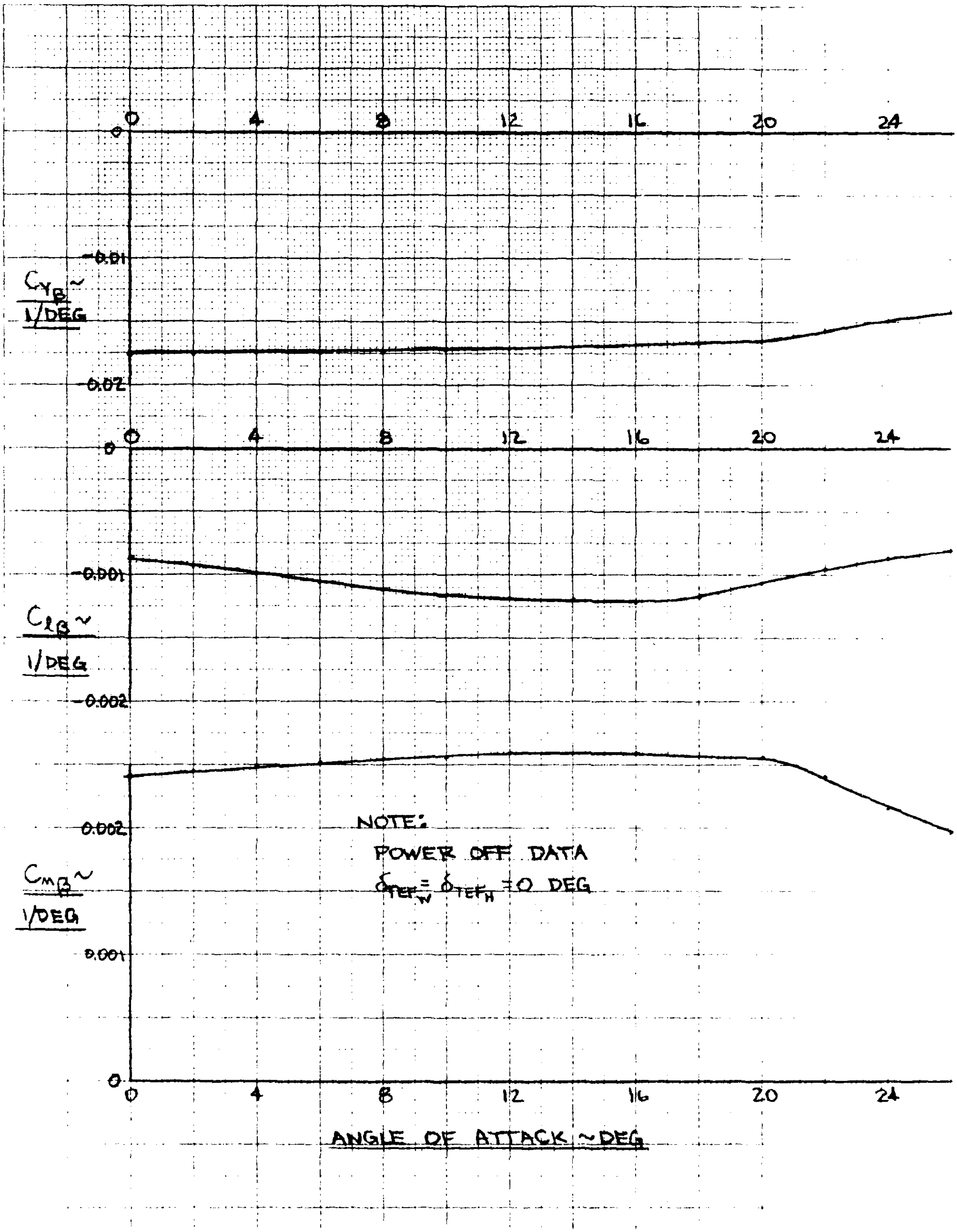


Figure B.2.3 - Tilt Nacelle Low Angle of Attack ($0 \leq \alpha \leq 30$ deg) Power Off Static Lateral Directional Derivatives

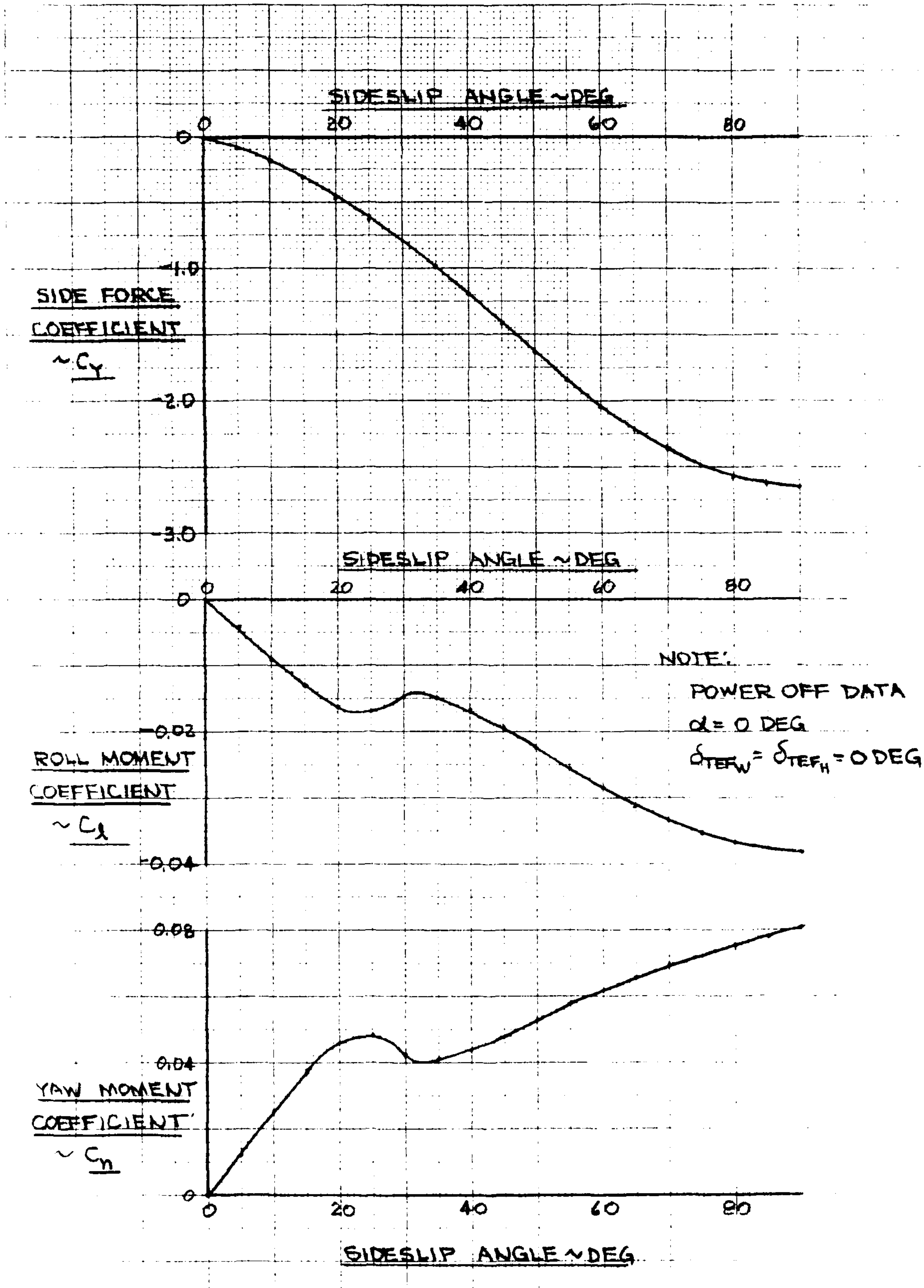


Figure B.2.4 - Tilt Nacelle Power Off Lateral Directional Aerodynamic Characteristics at Large Sideslip Angles (0 to 90 deg)

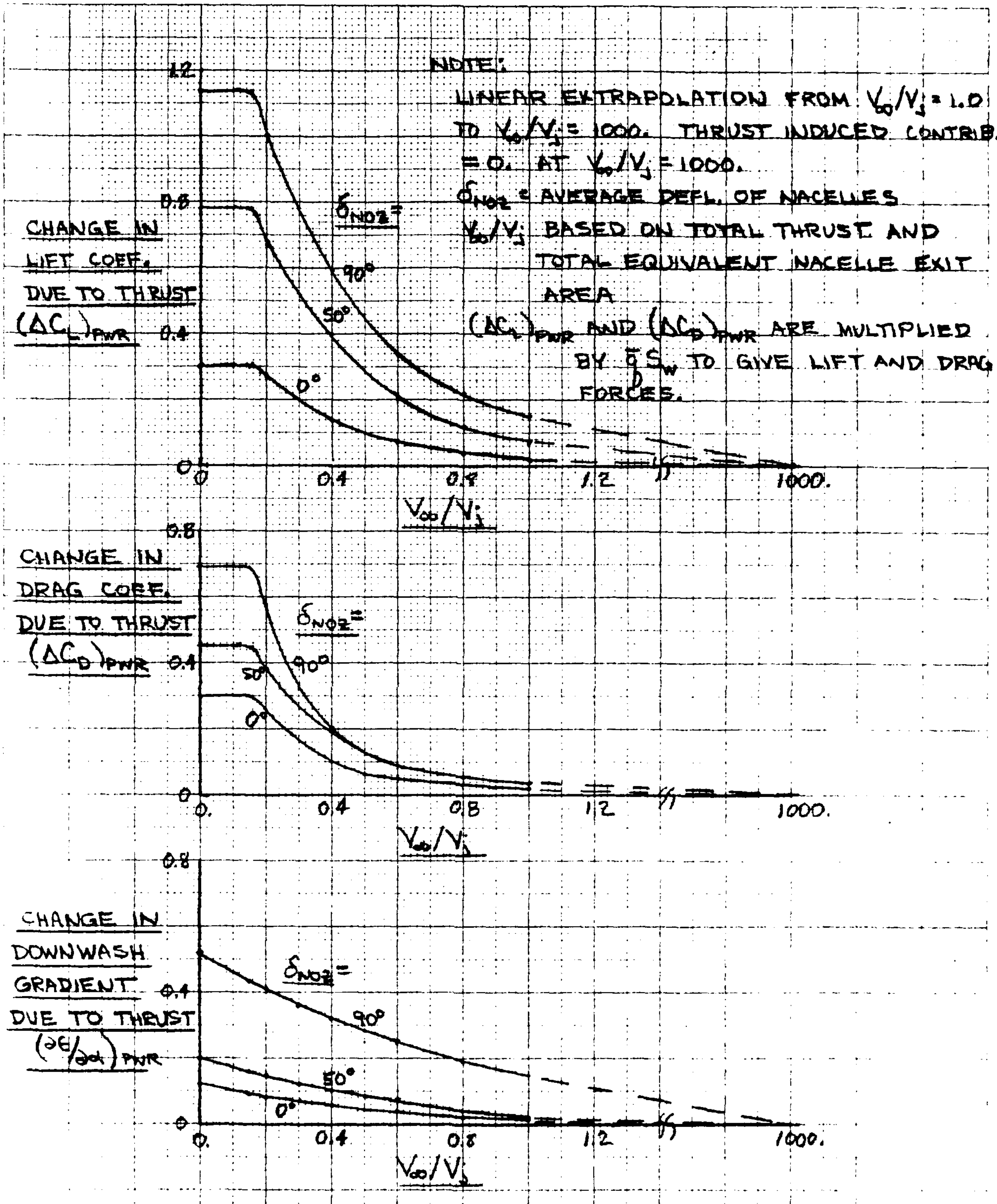


Figure B.2.5 - Tilt Nacelle Thrust + Induced Aerodynamic Characteristics

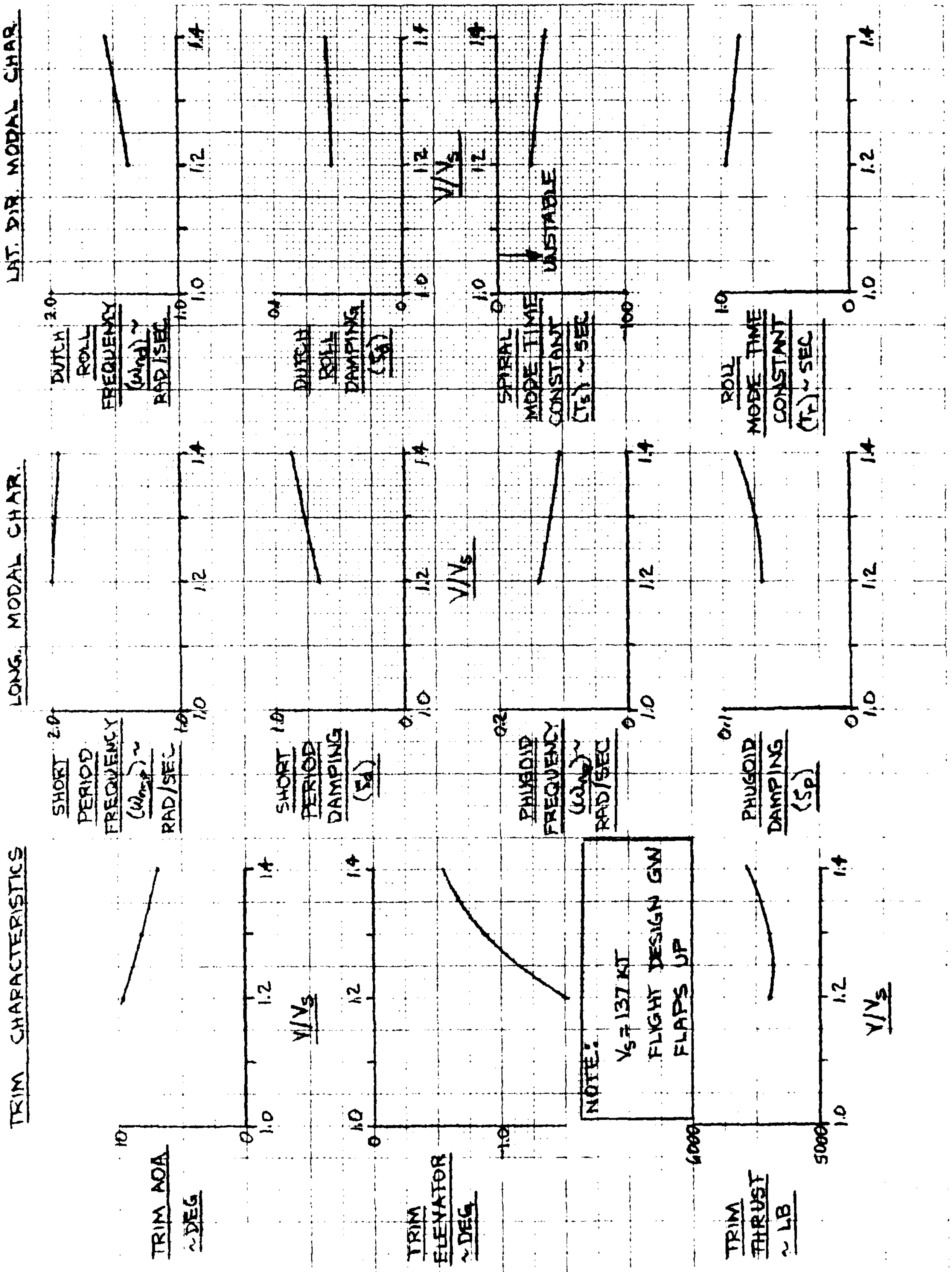


Figure B.2.6 - Tilt Nacelle Cruise Trim Summary

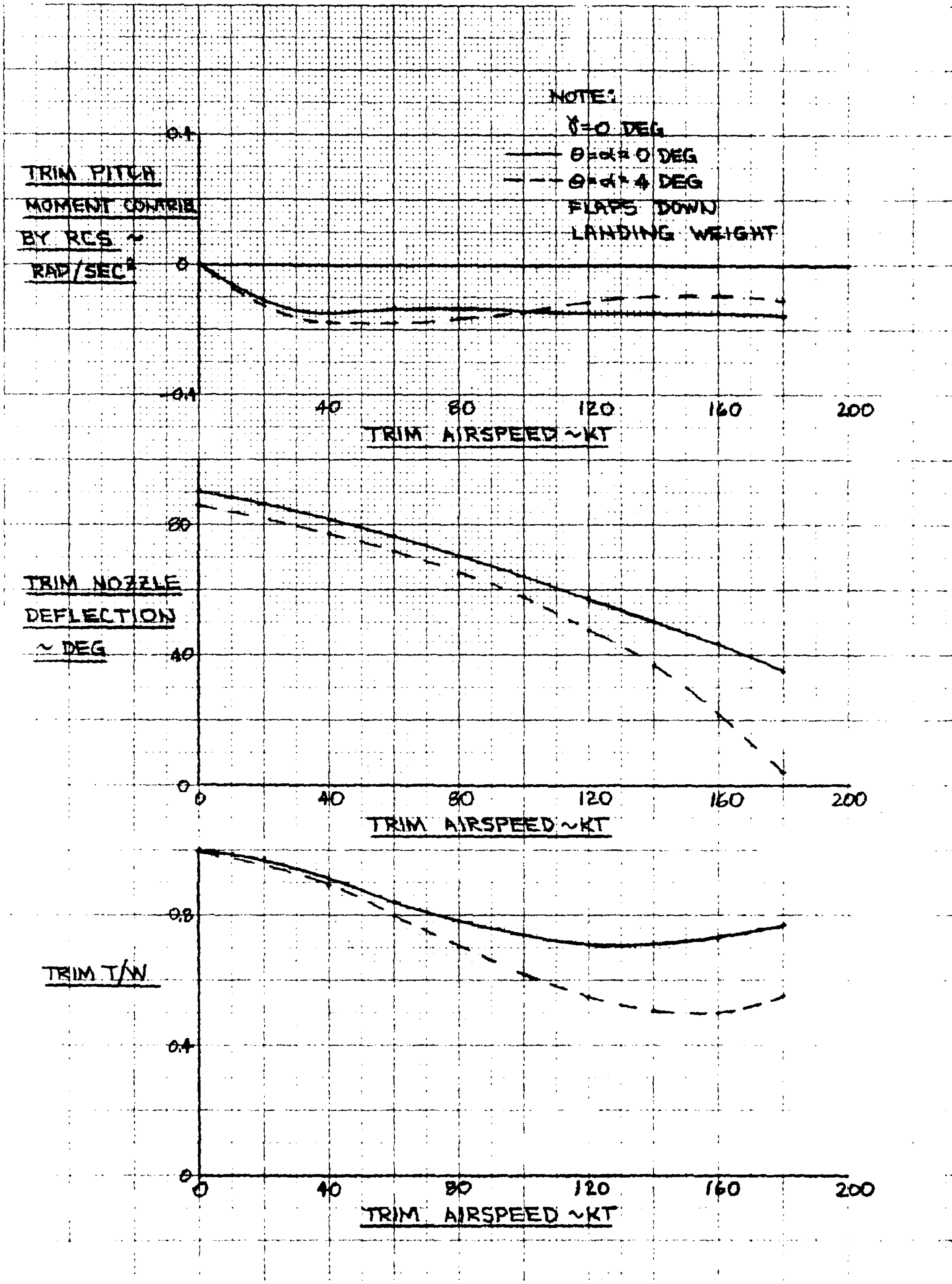


Figure B.2.7 - Tilt Nacelle Forward Flight Trim Summary

B.3 L + L/C Airplane Data

B.3.1 L + L/C Power Off Aerodynamics Data

Figures B.3.1 through B.3.4 summarize the power off aerodynamics of the L + L/C airplane. Horizontal tail incidence (i_H) is varied to trim the airplane in aerodynamic flight and fixed at zero incidence in the forward and hover flight regimes. The wing leading flap is set at 7 deg for conventional aerodynamic flight and at 20 deg in the flaps down configuration which is used in low speed cruise, forward, and hover flight. Also for the flaps down configuration, the wing trailing edge flap is set at 30 deg.

B.3.2 L + L/C Thrust-Induced Effects

The L + L/C thrust-induced effects model is based on data in reference (B-f). The model calculations are as follows:

$$\Delta L_{TI} = T_{TOT}\left(\frac{\Delta C_L}{T}\right)$$

$$\Delta D_{TI} = T_{TOT}\left(\frac{\Delta C_D}{T}\right)$$

$$\Delta M_{TI} = r_e T_{TOT}\left(\frac{\Delta C_m}{T r_e}\right)$$

$$\left(\frac{\partial \epsilon}{\partial \alpha}\right)_{TI} = f\left[\delta_{NOZ}, (V_\infty/V_j)\right]$$

$$\left(\frac{\Delta C_L}{T}\right) = \begin{cases} 0. & (V_\infty/V_j) < 0.08 \text{ or } > 1.0 \\ -0.39\sin(\delta_{NOZ})\left[\sin\left[\frac{\pi\left[(V_\infty/V_j) - 0.08\right]}{0.92}\right]\right]^{1.28} & 0.08 \le (V_\infty/V_j) \le 1.0 \end{cases}$$

$$\left(\frac{\Delta C_D}{T}\right) = \begin{cases} 0. & (V_\infty/V_j) > 1.0 \\ 0.40\sin(\delta_{NOZ})\left[\sin\left[\pi(V_\infty/V_j)\right]\right]^{2} & (V_\infty/V_j) \le 1.0 \end{cases}$$

$$\left(\frac{\Delta C_m}{T r_e}\right) = \begin{cases} 0. & (V_\infty/V_j) > 1.0 \\ 0.70\sin(\delta_{NOZ})\left[\sin\left[\pi(V_\infty/V_j)\right]\right]^{1.48} & (V_\infty/V_j) \le 1.0 \end{cases}$$

$$T_{TOT} = T_1 + T_2 + (T_3 + T_4) K_{LE}$$

$$r_e = r_{e_{L+L/C}} K_{LE} + r_{e_{L/C}} (1 - K_{LE})$$

$$K_{LE} = \begin{cases} 0 & \text{Lift engines off} \\ 1 & \text{Lift engines on} \end{cases}$$

$$(V_\infty / V_j) = \sqrt{\frac{2\bar{q}(\pi r_e^2)}{T_{TOT}}}$$

where

ΔL_{TI}, ΔD_{TI}, and ΔM_{TI} are the thrust-induced lift, drag, and pitching moment in the stability axis system. ΔL_{TI} and ΔD_{TI} have units of lb; ΔM_{TI} has units of ft lb.

$\left(\frac{\partial \epsilon}{\partial \alpha}\right)_{TI}$ is the thrust-induced downwash gradient. Plotted on figure B.3.5 as a function of δ_{NOZ} and (V_∞/V_j).

T_{TOT} is total thrust, lb

T_1 is the thrust of the left lift cruise engine.

T_2 is the thrust of the right lift cruise engine.

T_3 is the thrust of the front lift engine.

T_4 is the thrust of the rear lift engine.

$r_{e_{L+L/C}}$ is the equivalent radius of the total nozzle area of the propulsion system; includes both lift and lift cruise engines, ft

$r_{e_{L/C}}$ is the equivalent radius of the nozzle area of the two lift cruise engines, ft

$\overline{q}$ is dynamic pressure, lb/ft^2

δ_{NOZ} is the average deflection of the operating nozzles, deg

B.3.3 L + L/C Trim Summary

Tables B.3.1 through B.3.3 and figures B.3.6 and B.3.7 constitute the L + L/C trim summary. The following notes clarify certain table entries which are configuration specific:

1. The trim pitch moment applied by the propulsion system (Table B.3.1) represents different effects depending on flight regime. In hover and forward flight, the lift engines are operating and the airplane pitch moment is trimmed by adjusting the thrust balance between the lift (front) and lift/cruise (rear) engines. In cruise flight, the lift engines are not operating and the propulsion system derived pitch moment produced by the trim thrust of the lift/cruise engines must be trimmed by the aerodynamic pitch control surface.

2. In hover and forward flight with the lift engines operating one degree of positive yaw thrust deflection (δ_{YAW}) (Tables B.3.1 and B.3.3) is produced by one degree trailing edge right deflection of the lift engines yaw vanes and a simultaneous one degree trailing edge left deflection of the lift/cruise engines yaw vanes. This one degree of positive δ_{YAW} generates - 3.405 (= $N_{\delta_{YAW}}$)/57.3 = -0.0594 rad/sec^2 yaw acceleration when the airplane is hovered in a 35 kt headwind. Similarly in cruise flight with the lift engines not operating one degree of positive δ_{YAW} is produced by one degree trailing edge left deflection of the lift/cruise engines yaw vanes.

3. One pound of positive RCS pitch force (RCS_{PITCH}) (Table B.3.2) is produced by a one pound upward force at the nose RCS jet and a simultaneous one pound downward force at the tail RCS jet. Similarly one pound of positive RCS roll force (RCS_{ROLL}) (Table B.3.3) is produced by a one pound upward force at the left wing RCS jet and a simultaneous one pound downward force at the right wing RCS jet. The RCS is not available when the lift engines are not operating , thus the RCS derivatives are zero in cruise flight.

4. One pound of positive ΔT (Table B.3.2) is produced by simultaneous one pound increases at each of the operating nozzles; i.e., in forward and hover flight with the lift engines operating, one pound of positive ΔT produces a four pound increase in total thrust. In cruise flight with lift engines not operating, one pound of positive ΔT produces a two pound increase in total thrust.

Figure B.3.6 summarizes the cruise flight trim and modal characteristics of the L + L/C airplane while figure B.3.7 summarizes forward flight trim characteristics of the airplane.

Table B.3.1 Trim and Modal Characteristics of L + L/C Airplane

PARAMETER \ FLIGHT CONDITION	HOVER HEADWIND FLAPS DOWN	HOVER 45 DEG. CROSSWIND FLAPS DOWN	HOVER 90 DEG CROSSWIND FLAPS DOWN	FWD. FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT
- TRIM CHARACTERISTICS							
True Airspeed, kt	35.0	35.0	35.0	40.0	40.0	80.0	80.0
Pitch Angle, deg	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bank Angle, deg	0.0	- 3.42	- 6.39	0.0	0.0	0.0	0.0
Angle of Attack, deg	0.0	- 3.42	- 90.15	0.0	0.0	0.0	0.0
Sideslip Angle, deg	0.0	- 44.92	- 83.61	0.0	0.0	0.0	0.0
Total Thrust, lb	29010	29417	30036	28914	41696	28784	41176
Nozzle Deflection, deg	87.73	88.17	90.09	87.31	87.46	82.91	84.05
Trim Pitch Moment Appl. by Prop. Sys., ft-lb	-6220	-5285	- 2713	- 7295	-10394	- 16286	- 21124
Trim Roll Moment Appl. by RCS, ft-lb	0.0	- 6262	-10827	0.0	0.0	0.0	0.0
Yaw Thrust Defl, deg	0.0	4.40	10.29	0.0	0.0	0.0	0.0
Tail Incidence, deg	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table B.3.1 Trim and Modal Characteristics of L + L/C Airplane (Continued)

PARAMETER / FLIGHT CONDITION	HOVER HEADWIND FLAPS DOWN	HOVER 45 DEG. CROSSWIND FLAPS DOWN	HOVER 90 DEG CROSSWIND FLAPS DOWN	FWD. FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT
- MODAL CHARACTERISTICS*							
Longitudinal	[0.115,0.257 -0.409, 0.281] (-0.338) (-0.132)	[0.111,0.239 -0.421, 0.263] (-0.305) (-0.100)	[0.107,0.211 -0.452, 0.236] (-0.259) (-0.0378)	[0.160,0.236; -0.562,0.285] (-0.493) (-0.123)	[0.173,0.203 -0.649, 0.266] (-0.508) (-0.0870)	[0.185,0.220 -0.644, 0.288] (-0.735) (-0.181)	[0.222,0.213; -0.721,0.308] (-0.744) (-0.143)
Lateral	[0.235,0.512 -0.418, 0.563] (-0.663) (-0.0469)	[0.260,0.546 -0.430, 0.605] (-0.687) (-0.0910)	[0.287,0.582 -0.442, 0.649] (-0.721) (-0.0927)	[0.240,0.510; -0.426,0.564] (-0.698) (-0.0497)	[0.245,0.440 -0.486, 0.504] (-0.621) (-0.0575)	[0.209,0.627 -0.317, 0.661] (-0.855) (-0.0597)	[0.215,0.527; -0.377,0.570] (-0.691) (-0.0699)

*$[-\zeta\omega_n, \omega_n\sqrt{1-\zeta^2}; \zeta, \omega_n]$ indicates complex root pair located at $s = -\zeta\omega_n \pm j\omega_n\sqrt{1-\zeta^2}$ with natural frequency of ω_n rad/sec and damping ratio of ζ

(λ) indicates real root located at $s = \lambda$

Table B.3.1 Trim and Modal Characteristics of L + L/C Airplane (Continued)

DERIVATIVE \ FLIGHT CONDITION	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 1.4 V_s FLAPS UP FLT. DES. WGT
- TRIM CHARACTERISTICS						
True Airspeed, kt	120.0	120.0	120.0	160.0	200.0	205.8
Pitch Angle, deg	0.0	0.0	4.0	4.0	4.53	8.31
Bank Angle, deg	0.0	0.0	0.0	0.0	0.0	0.0
Angle of Attack, deg	0.0	0.0	4.0	4.0	4.53	8.31
Sideslip Angle, deg	0.0	0.0	0.0	0.0	0.0	0.0
Total Thrust, lb	29244	41718	23189	18014	4318	4035
Nozzle Deflection, deg	76.99	79.32	70.29	56.34	0.0	0.0
Trim Pitch Moment Appl. by Prop. Sys., ft-lb	-25342	-33156	-28193	-30776	-5397	-5044
Trim Roll Moment Appl. by RCS, ft-lb	0.0	0.0	0.0	0.0	0.0	0.0
Yaw Thrust Defl, deg	0.0	0.0	0.0	0.0	0.0	0.0
Tail Incidence, deg	0.0	0.0	0.0	0.0	0.08	-0.13

Table B.3.1 Trim and Modal Characteristics of L + L/C Airplane (Concluded)

DERIVATIVE \ FLIGHT CONDITION	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 1.4 V_s FLAPS UP FLT. DES. WGT
- MODAL CHARACTERISTICS						
Longitudinal	[0.203,0.198; -0.716,0.284] (-1.003) (-0.193)	[0.521,0.172; -0.825,0.304] (-0.980) (-0.160)	[0.262,0.108; -0.925,0.284] (-1.154) (-0.148)	(-1.490) (-0.0958) (0.490) (0.0963)	[-0.0171,0.124; 0.137,0.125] (-1.797) (0.653)	[-0.00479,0.131 0.0364,0.132] [-0.530,0.927; 0.496,1.068]
Lateral	[0.169,0.764; -0.217,0.782] (-1.004) (-0.0615)	[0.176, 0.644; -0.264,0.668] (-0.757) (-0.0749)	[0.156,0.913; -0.169, 0.927] (-0.999) (-0.0468)	[0.0941,1.128; -0.0831,1.132] (-1.114) (-0.0361)	[0.0253,1.419 -0.0178,1.420] (-1.217) (-0.0190)	[-0.0680,1.569; 0.0433,1.570] (-1.013) (-0.0138)

Table B.3.2 Longitudinal Stability Derivatives of L + L/C Airplane

DERIVATIVE / FLIGHT CONDITION	HOVER 35 KT HEADWIND FLAPS DOWN	HOVER 35 KT 45 DEG CROSSWIND FLAPS DOWN	HOVER 35 KT 90 DEG CROSSWIND FLAPS DOWN	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT
- X-DERIVATIVES							
X_u - ft/sec^2/ft/sec	-0.0256	-0.0234	-0.0192	-0.0284	-0.0229	-0.0439	-0.0321
X_w - ft/sec^2/ft/sec	0.00297	-0.00211	-0.00023	0.00334	0.00257	0.00580	0.00448
X_q - ft/sec^2/rad/sec	-0.0669	-0.061	-0.0422	-0.0689	-0.0633	-0.0862	-0.0747
X_{i_H} - ft/sec^2/rad	-0.00200	-0.00194	0.00402	-0.00261	-0.00182	-0.0105	-0.00727
$X_{RCS_{PITCH}}$ - ft/sec^2/lb	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$X_{\delta_{NOZ}}$ - ft/sec^2/rad	-31.80	-32.16	-32.41	-31.70	-31.80	-31.55	-31.38
$X_{\Delta T}$ - ft/sec^2/lb	0.00005	0.00005	0.0	0.00007	0.00002	0.00030	0.00012
- Z-DERIVATIVES							
Z_u - ft/sec^2/ft/sec	-0.0117	-0.00276	-0.00060	-0.0147	-0.00835	0.00209	-0.00042
Z_w - ft/sec^2/ft/sec	-0.149	-0.103	-0.0388	-0.168	-0.122	-0.323	-0.229
Z_q - ft/sec^2/rad/sec	-0.274	-0.276	-0.0846	-0.305	-0.233	-0.550	-0.404
Z_{i_H} - ft/sec^2/rad	-1.287	-0.755	0.00075	-1.681	-1.170	-6.725	-4.679
$Z_{RCS_{PITCH}}$ - ft/sec^2/lb	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$Z_{\delta_{NOZ}}$ - ft/sec^2/rad	-1.266	-1.038	0.0446	-1.496	-1.416	-3.774	-3.216
$Z_{\Delta T}$ - ft/sec^2/lb	- 0.00438	-0.00438	-0.00433	-0.00438	-0.00307	-0.00450	-0.00312

B.3.2 Longitudinal Stability Derivatives of L + L/C Airplane (Continued)

DERIVATIVE \ FLIGHT CONDITION	HOVER 35 KT HEADWIND FLAPS DOWN	HOVER 35 KT 45 DEG CRCSSWIND FLAPS DOWN	HOVER 35 KT 90 DEG CROSSWIND FLAPS DOWN	FWD. FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD. FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT.
- M-DERIVATIVES							
M_u - rad/sec^2/ft/sec	0.00082	0.00066	0.00045	0.00101	0.00091	0.00105	0.00138
M_w - rad/sec^2/ft/sec	0.00109	0.00065	0.00081	0.00112	0.00157	0.00138	0.00175
M_q - rad/sec^2/rad/sec	-0.0655	-0.0575	-0.0248	-0.0719	-0.0788	-0.124	-0.129
M_{i_w} - rad/sec^2/rad	-0.147	-0.0862	-0.00009	-0.192	-0.187	-0.768	-0.749
$M_{RCS_{PITCH}}$ - rad/sec^2/lb	0.00044	0.00044	0.00044	0.00044	0.00043	0.00044	0.00043
$M_{\delta_{NOZ}}$ - rad/sec^2/rad	-0.326	-0.330	-0.329	-0.326	-0.458	-0.334	-0.462
$M_{\Delta T}$ - rad/sec^2/lb	-0.00013	-0.00013	-0.00013	-0.00013	-0.00013	-0.00012	-0.00012

Table. B.3.2 Longitudinal Stability Derivatives of L + L/C Airplane (Continued)

PARAMETER \ FLIGHT CONDITION	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT.	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 1.4 V_s FLAPS UP FLT. DES. WGT.
- X-DERIVATIVES						
X_u - ft/sec^2/ft/sec	-0.0546	-0.0436	-0.0504	-0.0440	-0.017	- 0.00530
X_w - ft/sec^2/ft/sec	0.00775	0.00586	0.0354	0.0478	0.0682	0.0876
X_q - ft/sec^2/rad/sec	-0.104	-0.0872	-0.121	-0.131	-0.122	0.117
X_{i_H} - ft/sec^2/rad	-0.0235	-0.0164	-0.00954	-0.0121	-0.0515	0.259
$X_{RCS_{PITCH}}$ - ft/sec^2/lb	0.0	0.0	0.0	0.0	0.0	0.0
$X_{\delta_{NOZ}}$ - ft/sec^2/rad	-32.09	-31.78	-25.24	-9.10	-1.971	-1.493
$X_{\Delta T}$ - ft/sec^2/lb	0.00059	0.00031	0.00106	0.00150	0.00197	0.00157
- Z-DERIVATIVES						
Z_u - ft/sec^2/ft/sec	-0.00428	-0.00051	-0.0441	-0.0753	-0.126	-0.0975
Z_w - ft/sec^2/ft/sec	-0.478	-0.336	-0.500	-0.662	-0.813	-0.599
Z_q - ft/sec^2/rad/sec	-0.798	-0.578	-0.517	-0.668	-0.798	-1.555
Z_{i_H} - ft/sec2/rad	-15.13	-10.53	-12.93	-23.03	-35.36	-43.23
$Z_{RCS_{PITCH}}$ - ft/sec^2/lb	0.0	0.0	0.0	0.0	0.0	0.0
$Z_{\delta_{NOZ}}$ - ft/sec^2/rad	-6.514	-5.527	-7.547	-3.792	-2.926	-2.190
$Z_{\Delta T}$ - ft/sec^2/lb	-0.00436	-0.00309	-0.00419	-0.00353	-0.00002	-0.00003

Table B.3.2 Longitudinal Stability Derivatives of L + L/C Airplane (Concluded)

PARAMETER / FLIGHT CONDITION	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT.	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 1.4 V_s FLAPS UP FLT. DES. WGT.
- M-DERIVATIVES						
M_u - rad/sec^2/ft/sec	0.00103	0.00134	0.00107	0.00069	-0.00010	0.00058
M_w - rad/sec^2/ft/sec	0.00167	0.00203	0.00278	0.00344	0.00395	-0.00272
M_q - rad/sec^2/rad/sec	-0.176	-0.180	-0.149	-0.191	-0.223	-0.323
M_{i_H} - rad/sec^2/rad	-1.727	-1.685	-1.477	-2.629	-4.040	-6.111
$M_{RCS_{PITCH}}$ - rad/sec^2/lb	0.00044	0.00043	0.00044	0.00044	0.0	0.0
$M_{\delta_{NOZ}}$ - rad/sec^2/rad	-0.357	-0.489	-0.312	-0.719	-0.651	-0.581
$M_{\Delta T}$ - rad/sec^2/lb	-0.00011	-0.00011	-0.00010	-0.00006	-0.00001	-0.00001

Table B.3.3 Lateral Stability Derivatives of L + L/C Airplane

DERIVATIVE \ FLIGHT CONDITION	HOVER 35 KT HEADWIND FLAPS DOWN	HOVER 35 KT 45 DEG CROSSWIND FLAPS DOWN	HOVER 35 KT 90 DEG CROSSWIND FLAPS DOWN	FWD. FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD. FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT.
- Y-DERIVATIVES							
Y_v - ft/sec^2/ft/sec	-0.0379	-0.108	-0.150	-0.0405	-0.0344	-0.0637	-0.0485
Y_p - ft/sec^2/rad/sec	-0.0116	0.00595	-0.00448	-0.0207	0.00099	-0.0927	-0.0497
Y_r - ft/sec^2/rad/sec	0.329	0.255	0.303	0.367	0.275	0.666	0.484
Y_{δ_A} - ft/sec^2/rad	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$Y_{RCS_{ROLL}}$ - ft/sec^2/lb	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Y_{δ_R} - ft/sec^2/rad	0.510	0.114	0.0	0.666	0.463	2.664	1.853
$Y_{\delta_{YAW}}$ - ft/sec^2/rad	-7.539	-7.726	-8.110	-7.438	-7.460	-6.680	-6.795
- L-DERIVATIVES							
L_v - rad/sec^2/ft/sec	-0.00641	-0.00397	-0.00389	-0.00688	-0.00490	-0.0110	-0.00698
L_p - rad/sec^2/rad/sec	-0.160	-0.114	-0.0482	-0.182	-0.107	-0.361	-0.212
L_r - rad/sec^2/rad/sec	0.0885	0.0404	0.0348	0.101	0.0593	0.201	0.118
L_{δ_A} - rad/sec^2/rad	-0.286	-0.122	0.0	-0.374	-0.219	-1.495	-0.875
$L_{RCS_{ROLL}}$ - rad/sec^2/lb	0.00193	0.00193	0.00193	0.00193	0.00113	0.00193	0.00113
L_{δ_R} - rad/sec^2/rad	0.0736	0.0164	0.0	0.0961	0.0563	0.384	0.225
$L_{\delta_{YAW}}$ - rad/sec^2/rad	1.577	1.586	1.558	1.582	1.333	1.678	1.385

Table B.3.3 Lateral Stability Derivatives of L + L/C Airplane (Continued)

DERIVATIVE \ FLIGHT CONDITION	HOVER 35 KT HEADWIND FLAPS DOWN	HOVER 35 KT 45 DEG CROSSWIND FLAPS DOWN	HOVER 35 KT 90 DEG CROSSWIND FLAPS DOWN	FWD. FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD. FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT.
- N-DERIVATIVES							
N_v - rad/sec^2/ft/sec	-0.00020	-0.0137	-0.0200	-0.00006	-0.00060	0.00085	0.00040
N_p - rad/sec^2/rad/sec	0.00686	0.00923	0.0102	0.00718	0.00808	0.00986	0.0104
N_r - rad/sec^2/rad/sec	-0.0446	-0.0382	-0.0450	-0.0487	-0.0499	-0.0776	-0.0759
N_{δ_A} - rad/sec^2/rad	0,00184	0.00125	-0.00017	0.00240	0.00213	0.00960	0.00853
$N_{RCS_{ROLL}}$ - rad/sec^2/lb	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N_{δ_R} - rad/sec^2/rad	-0.467	-0.0121	0.0	-0.0610	-0.0541	-0.244	-0.217
$N_{\delta_{YAW}}$ - rad/sec^2/rad	-3.405	-3.450	-3.506	-3.396	-4.349	-3.371	-4.296

Table B.3.3 Lateral Stability Derivatives of L + L/C Airplane (Continued)

DERIVATIVE \ FLIGHT CONDITION	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 1.4 V_S FLAPS UP FLT. DES. WGT.
- Y-DERIVATIVES						
Y_v - $ft/sec^2/ft/sec$	-0.0882	-0.0654	-0.0849	-0.107	-0.124	-0.102
Y_p - $ft/sec^2/rad/sec$	-0.164	-0.0996	-0.175	-0.255	-0.354	-0.289
Y_r - $ft/sec^2/rad/sec$	0.969	0.696	0.960	1.260	1.540	1.254
Y_{δ_A} - $ft/sec^2/rad$	0.0	0.0	0.0	0.0	0.0	0.0
$Y_{RCS_{ROLL}}$ - $ft/sec^2/lb$	0.0	0.0	0.0	0.0	0.0	0.0
Y_{δ_R} - $ft/sec^2/rad$	5.994	4.170	5.965	10.60	16.55	13.82
$Y_{\delta_{YAW}}$ - $ft/sec^2/rad$	-5.924	-6.140	-3.826	-1.120	4.740	3.547
- L-DERIVATIVES						
L_v - $rad/sec^2/ft/sec$	-0.0153	-0.00951	-0.0202	-0.0259	-0.0320	-0.0307
L_p - $rad/sec^2/rad/sec$	-0.539	-0.317	-0.552	-0.735	-0.921	-0.927
L_r - $rad/sec^2/rad/sec$	0.301	0.177	0.484	0.645	0.846	0.744
L_{δ_A} - $rad/sec^2/rad$	-3.363	-1.969	-3.770	-6.703	-10.36	-8.229
$L_{RCS_{ROLL}}$ - $rad/sec^2/lb$	0.00193	0.00113	0.00193	0.00193	0.0	0.0
L_{δ_R} - $rad/sec^2/rad$	0.865	0.506	0.861	1.530	2.387	2.408
$L_{\delta_{YAW}}$ - $rad/sec^2/rad$	1.866	1.503	1.661	1.568	-0.246	-0.223

Table B.3.3 Lateral Stability Derivatives of L + L/C Airplane (Concluded)

DERIVATIVE / FLIGHT CONDITION	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 1.4 V_s FLAPS UP FLT. DES. WGT.
- N-DERIVATIVES						
N_v - rad/sec^2/ft/sec	0.00165	0.00112	0.00175	0.00266	0.00387	0.00373
N_p - rad/sec^2/rad/sec	0.0126	0.0128	-0.00640	-0.0104	-0.0200	-0.0272
N_r - rad/sec^2/rad/sec	-0.107	-0.102	-0.107	-0.135	-0.157	-0.145
N_{δ_A} - rad/sec^2/rad	0.0216	0.0192	0.0142	0.0253	0.0353	-0.0624
$N_{RES\ ROLL}$ - rad/sec^2/lb	0.0	0.0	0.0	0.0	0.0	0.0
N_{δ_R} - rad/sec^2/rad	-0.549	-0.487	-0.546	-0.970	-1.514	-1.551
$N_{\delta_{YAW}}$ - rad/sec^2/rad	-3.414	-4.335	-2.755	-2.306	-0.624	-0.573

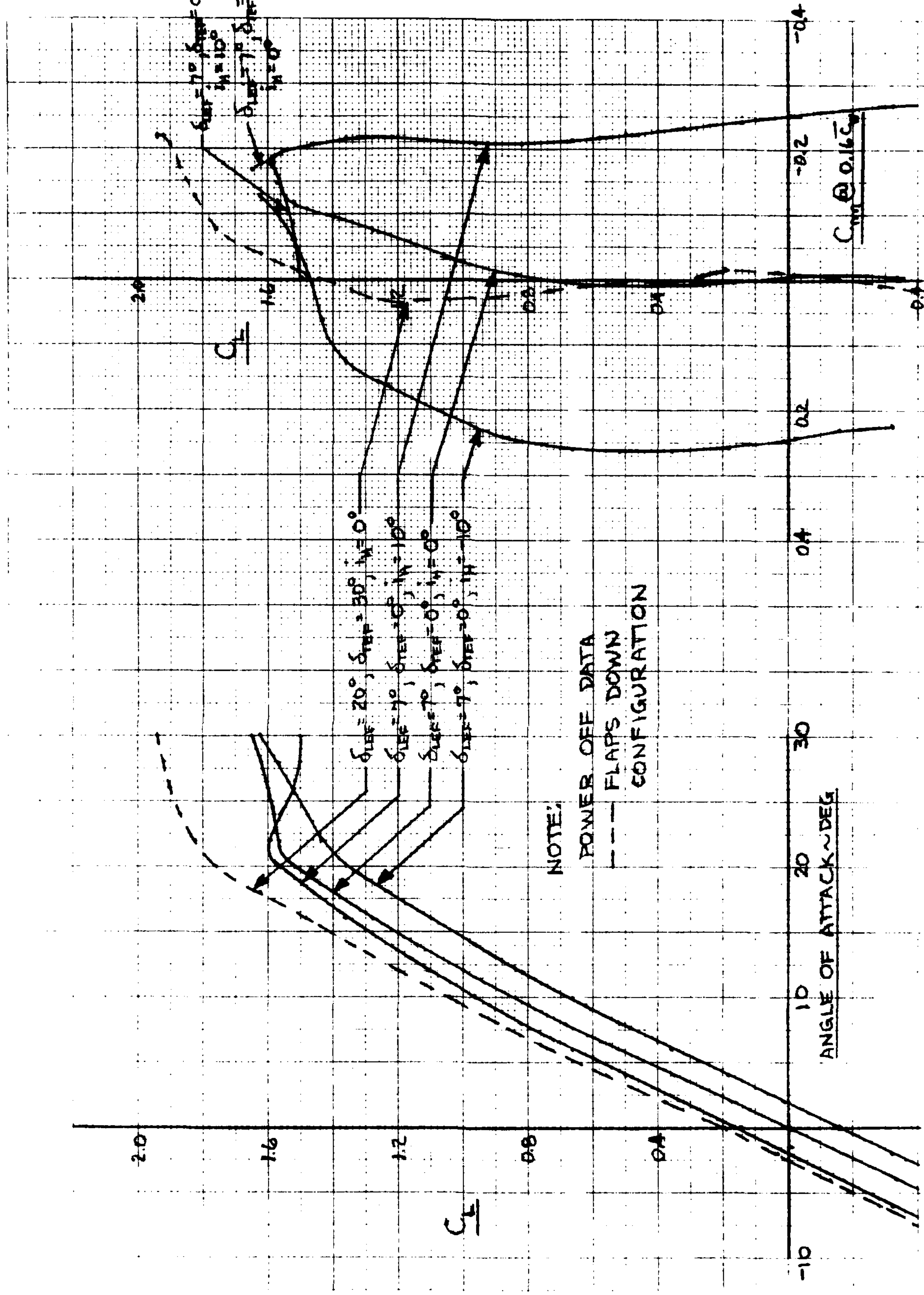


Figure B.3.1 - L + L/C Low Angle of Attack ($0 \leq \alpha \leq 30$ deg) Power Off Longitudinal Aerodynamic Characteristics

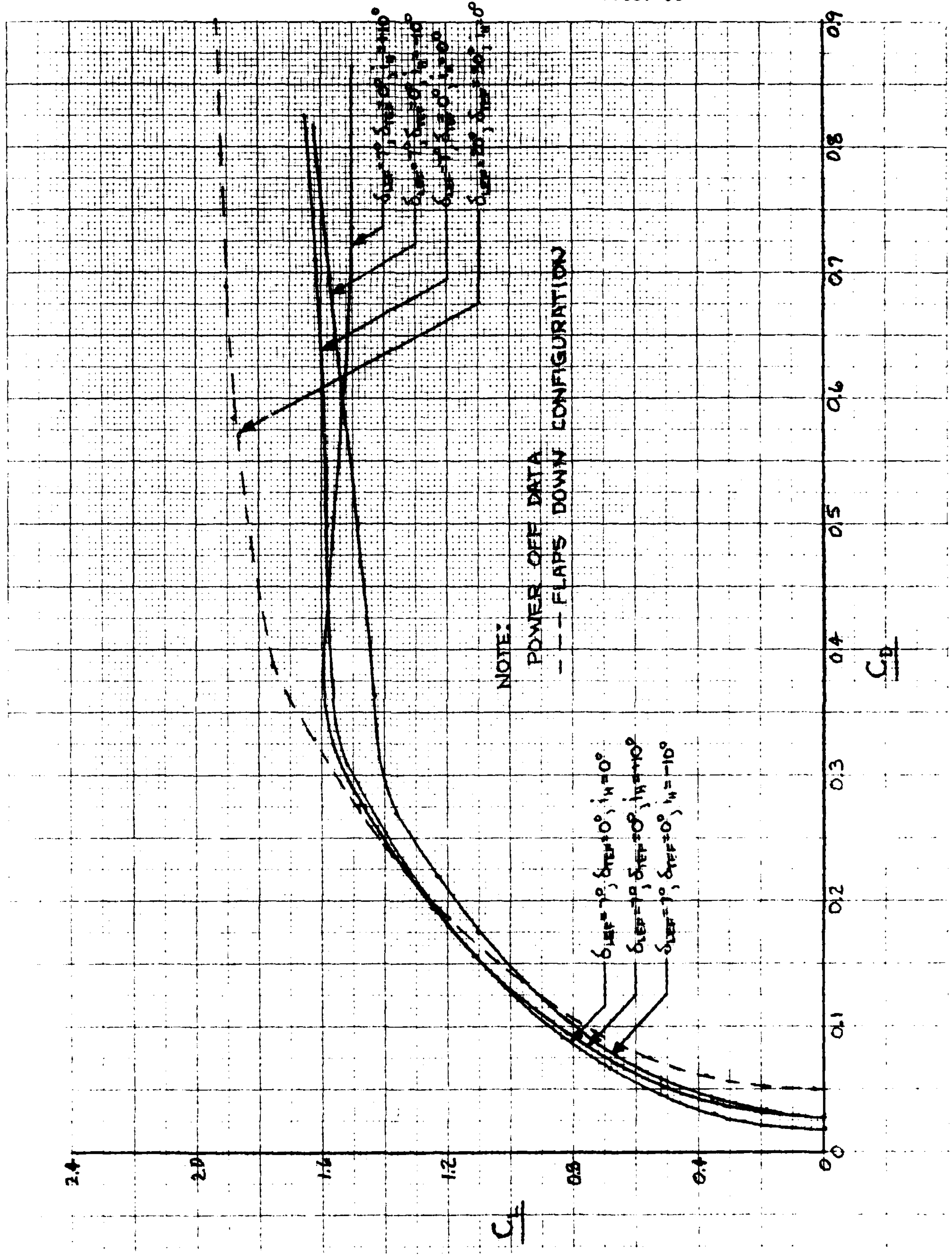


Figure B.3.1 (Cont.) - L + L/C Low Angle of Attack (0 ≤ α ≤ 30 deg) Power Off Longitudinal Aerodynamic Characteristics

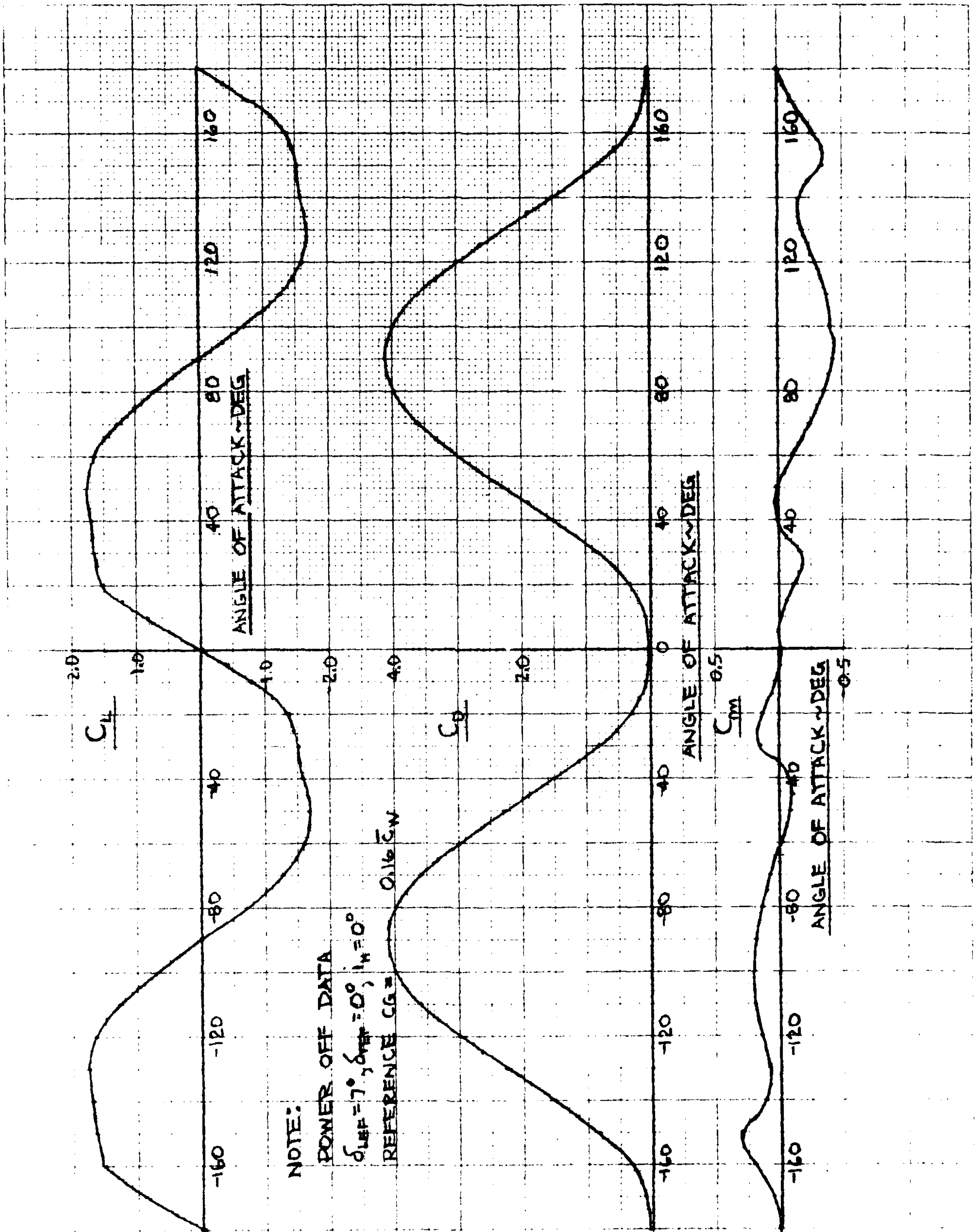


Figure B.3.2 - L + L/C High Angle of Attack (to $\pm$ 180 deg) Power Off Longitudinal Aerodynamic Characteristics

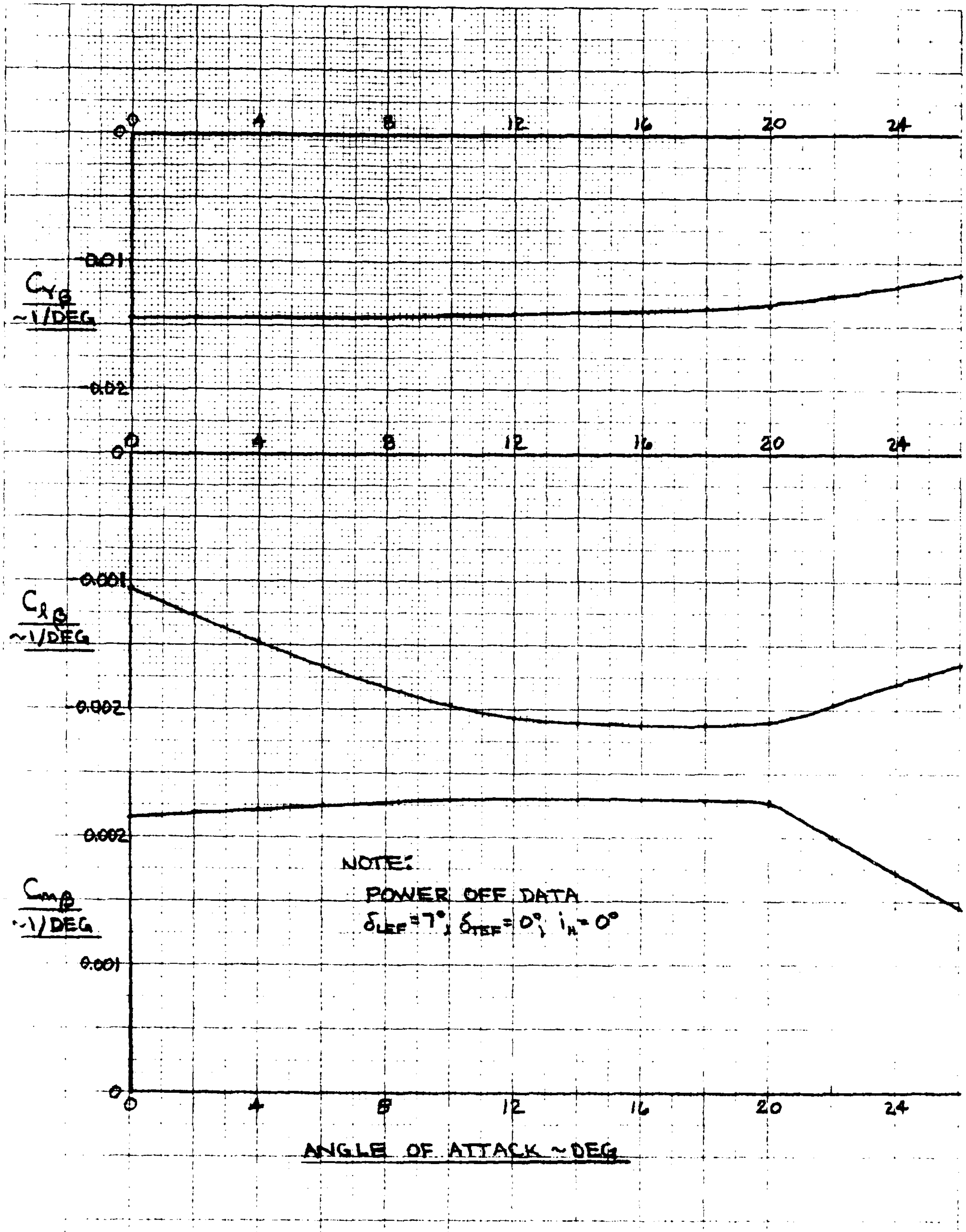


Figure B.3.3 - L + L/C Low Angle of Attack (0 ≤ α ≤ 30 deg) Power Off Static Lateral Directional Derivatives

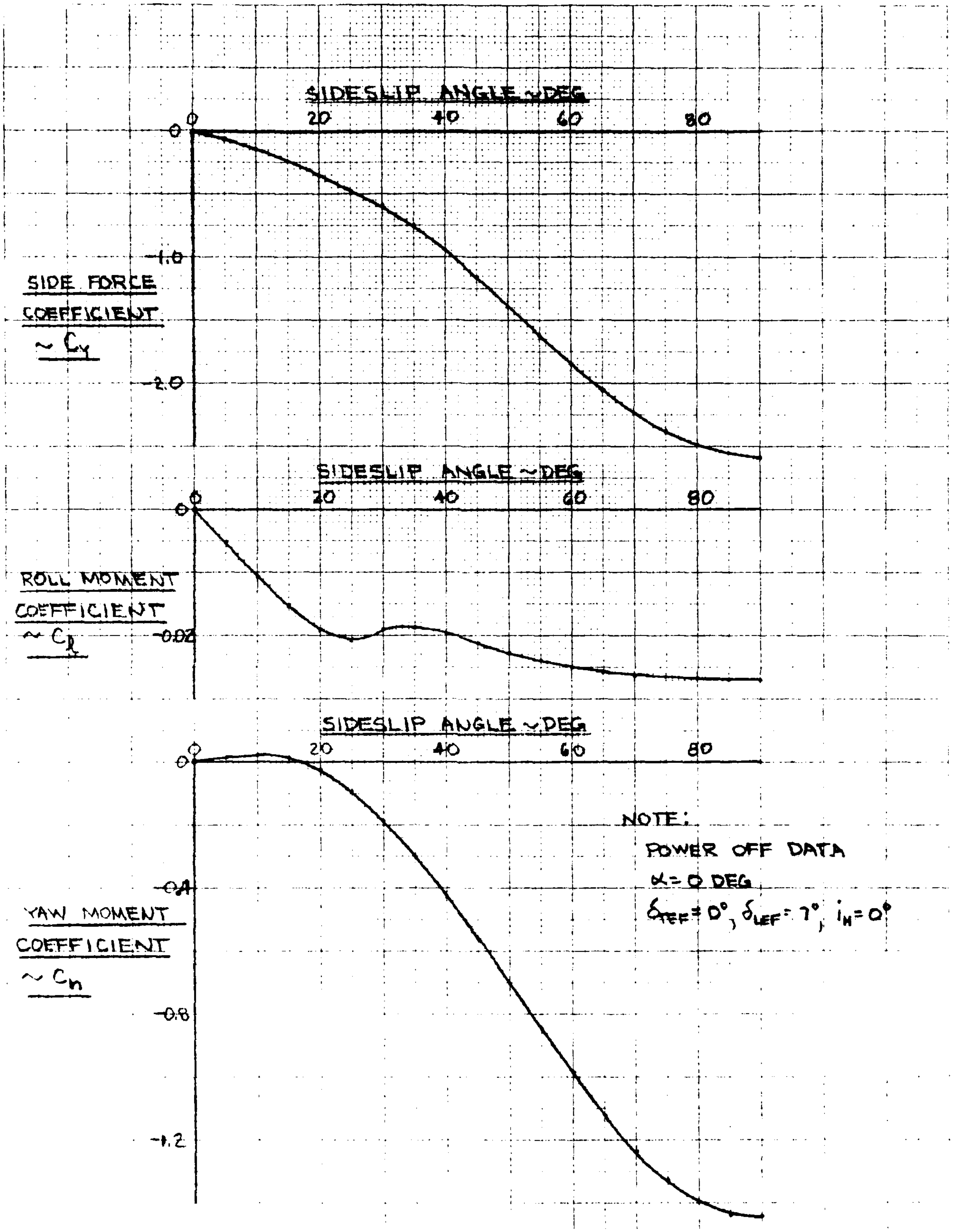


Figure B.3.4 - L + L/C Power Off Lateral Directional Aerodynamic Characteristics at Large Sideslip Angles (0 to 90 deg)

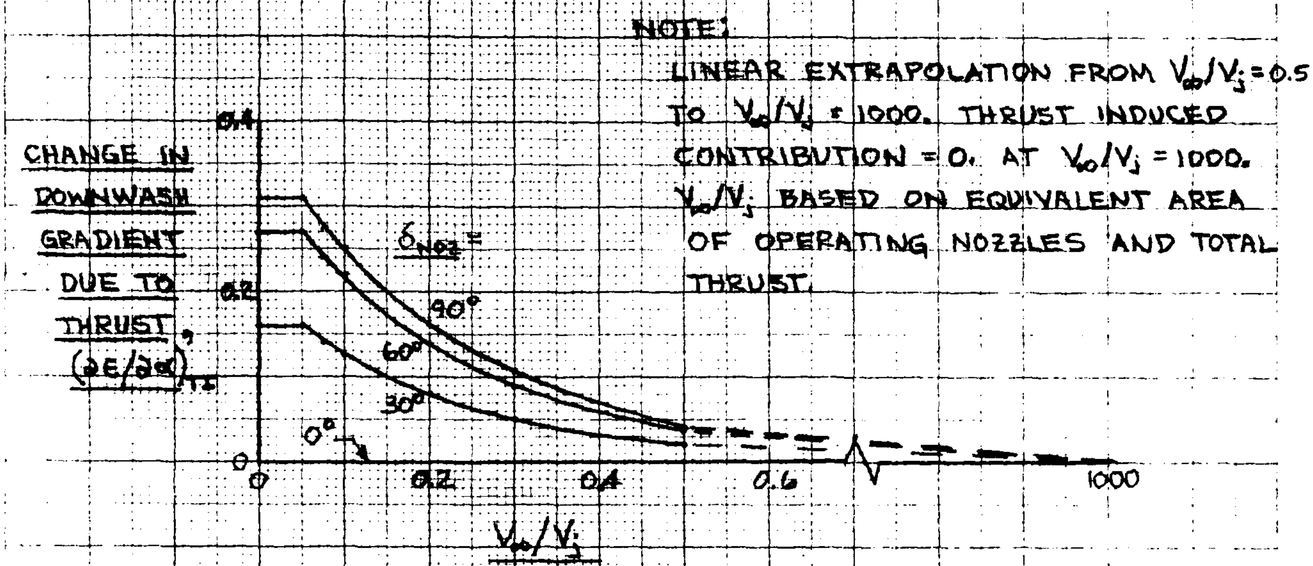


Figure B.3.5 - L + L/C Thrust - Induced Downwash Gradient Characteristics

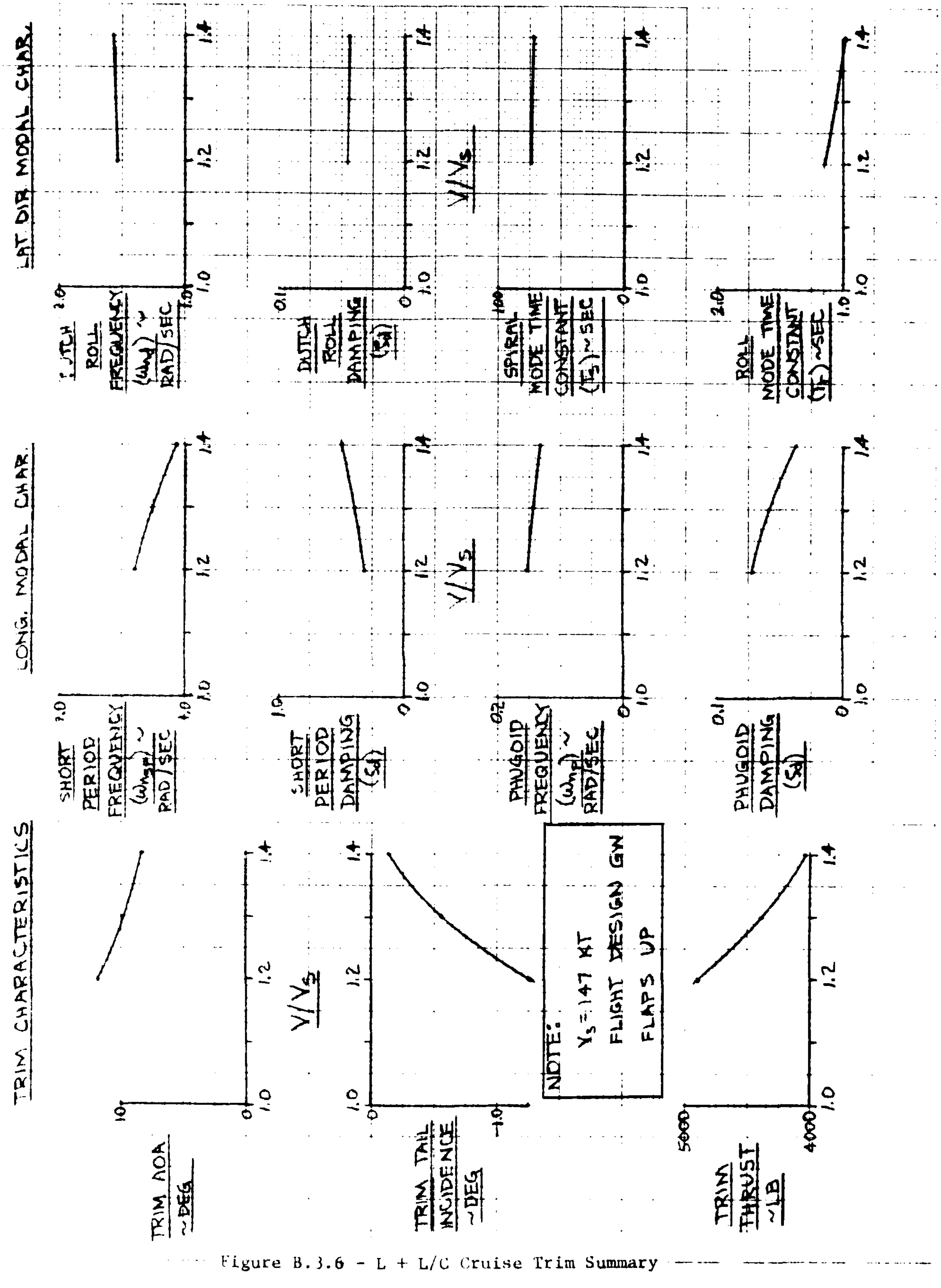


Figure B.3.6 - L + L/C Cruise Trim Summary

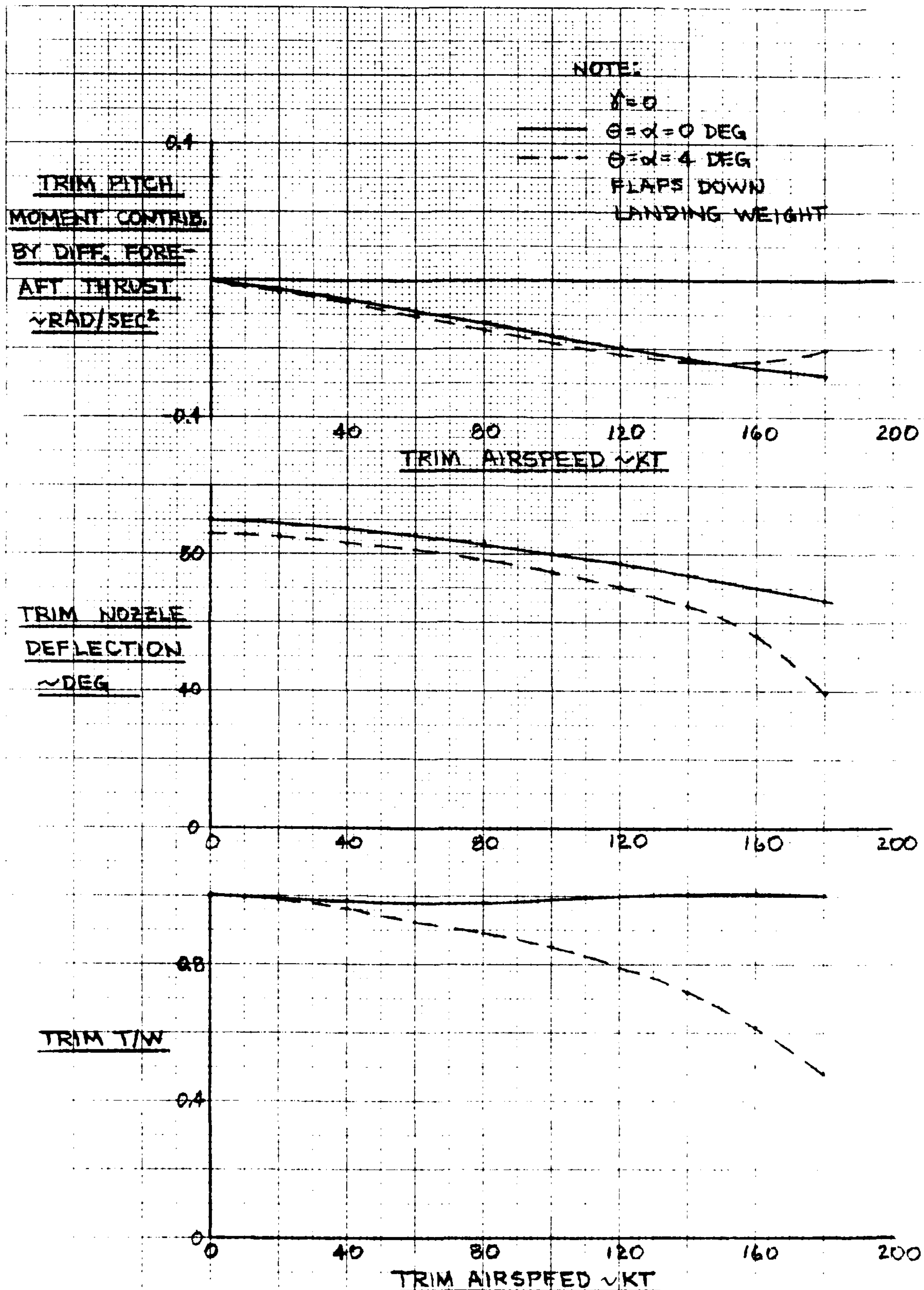


Figure B.3.7 - L + L/C Forward Flight Trim Summary

B.4 RALS Airplane Data

B.4.1 RALS Power Off Aerodynamic Data

Figures B.4.1 through B.4.4 summarize the power off aerodynamics of the RALS airplane. These data include the effects of the full time angle of attack schedule developed for canard incidence to linearize the low angle of attack aerodynamics. Symmetric deflection of the wing trailing edge flaps (elevons) is varied to trim the airplane in aerodynamic flight. For the flaps down configuration both the wing trailing edge and leading edge flaps are set at 20 deg.

B.4.2 RALS Thrust-Induced Effects

The RALS thrust-induced effects model is based on data in reference (B-f). The model calculations are as follows:

$$\Delta L_{TI} = T_{TOT}\left(\frac{\Delta C_L}{T}\right)$$

$$\Delta D_{TI} = T_{TOT}\left(\frac{\Delta C_D}{T}\right)$$

$$\Delta M_{TI} = T_{TOT}\, r_e \left(\frac{\Delta C_m}{T\, r_e}\right)$$

$$\left(\frac{\Delta C_L}{T}\right) = \begin{cases} 0. & (V_\infty/V_j) < 0.08 \text{ or } > 1.0 \\ -0.39 \sin(\delta_{NOZ})\left[\sin\left[\frac{\pi\left[(V_\infty/V_j)-0.08\right]}{0.92}\right]\right]^{1.28} & 0.08 \le (V_\infty/V_j) \le 1.0 \end{cases}$$

$$\left(\frac{\Delta C_D}{T}\right) = \begin{cases} 0. & (V_\infty/V_j) > 1.0 \\ 0.40 \sin(\delta_{NOZ})\left[\sin\left[\pi(V_\infty/V_j)\right]\right]^2 & (V_\infty/V_j) \le 1.0 \end{cases}$$

$$\left(\frac{\Delta C_m}{T r_e}\right) = \begin{cases} 0. & (V_\infty/V_j) > 1.0 \\ 0.70 \sin(\delta_{NOZ})\left[\sin\left[\pi(V_\infty/V_j)\right]\right]^{1.48} & (V_\infty/V_j) \le 1.0 \end{cases}$$

$$T_{TOT} = (T_1 + T_2) K_{FN} + T_3 + T_4$$

$$r_e = r_{e_{F+R}} K_{FN} + r_{e_R}(1 - K_{FN})$$

$$K_{FN} = \begin{cases} 1 & \text{Front nozzles operating} \\ 0 & \text{Front nozzles not operating} \end{cases}$$

$$(V_\infty/V_j) = \sqrt{\frac{2\bar{q}(\pi r_e^2)}{T_{TOT}}}$$

where

ΔL_{TI}, ΔD_{TI}, and ΔM_{TI} are the thrust-induced lift, drag, and pitching moment in the stability axis system. ΔL_{TI} and ΔD_{TI} have units of lb; ΔM_{TI} has units of ft lb.

T_{TOT} is total thrust, lb

T_1 is the thrust of the left front nozzle, lb

T_2 is the thrust of the right front nozzle, lb

T_3 is the thrust of the left rear nozzle, lb

T_4 is the thrust of the right rear nozzle, lb

$r_{e_{F+R}}$ is the equivalent radius of the total nozzle area of the propulsion system; includes both front and rear nozzles, ft

r_{e_R} is the equivalent radius of the total area of the two rear nozzles, ft

$\bar{q}$ is dynamic pressure, lb/ft^2

δ_{NOZ} is the average deflection of the operating nozzles, deg

B.4.3 RALS Trim Summary

Tables B.4.1 through B.4.3 and figures B.4.5 and B.4.6 constitute the RALS trim summary. The following notes clarify certain table entries which are configuration specific:

1. The trim pitch moment applied by the propulsion system (Table B.4.1) represents different effects depending on flight regime. In hover and forward flight, the front nozzles are open and the airplane pitch moment is trimmed by adjusting the thrust balance between the front and rear nozzles. In cruise flight, the front nozzles are closed and the propulsion system derived pitch moment produced by the trim thrust of the rear nozzles (equals zero for the cases in Table B.4.1) must be trimmed by the aerodynamic pitch control surface.

2. In hover and forward flight when the front nozzles are open one degree of positive yaw thrust deflection (δ_{YAW}) (Tables B.4.1 and B.4.3) is produced by one degree trailing edge right deflecton of the front nozzles yaw vanes and a simultaneous one degree trailing edge left deflection of the rear nozzles yaw vanes. This one degree of positive δ_{YAW} generates -3.606 ($= N_{\delta_{YAW}}$)/57.3 = -0.0629 rad/sec^2 yaw acceleration when the airplane is hovered in a 35 kt headwind. Similarly in cruise flight with the front nozzles closed one degree of positive δ_{YAW} is produced by one degree trailing edge left deflection of the rear nozzles yaw vanes.

3. One pound of positive ΔT (Table B.4.2) is produced by simultaneous one pound increases at each of the operating nozzles; i.e., in forward and hover flight with the front nozzles open, one pound of positive ΔT produces a four pound increase in total thrust, in cruise flight with the front nozzles closed, one pound of positive ΔT produces a two pound increase in total thrust.

4. One pound of positive ΔT_{PITCH} (Table B.4.2) is produced by one pound thrust increases at each front nozzle and simultaneous one pound thrust decreases at each rear nozzle. This one pound of positive

T_{PITCH} generates 0.00051 (= $M_{\Delta T_{PITCH}}$) rad/sec^2 pitch acceleration when the airplane is hovered in a 35 kt headwind. Note that with front nozzles closed (cruise flight) the ΔT_{PITCH} derivatives are the negative of the ΔT derivaties.

5. One pound of positive RCS roll force (RCS_{ROLL}) (Table B.4.3) is produced by a one pound upward force at the left wing RCS jet and a simultaneous one pound downward force at the right wing RCS jet. The RCS is not available when the front nozzles are closed, thus the RCS derivatives are zero in cruise flight.

Figure B.3.5 summarizes the cruise flight trim and modal characteristics of the RALS airplane while figure B.3.6 summarizes forward flight trim characteristics of the airplane.

Table B.4.1 Trim and Modal Characteristics of RALS Airplane

PARAMETER / FLIGHT CONDITION	HOVER HEADWIND FLAPS DOWN	HOVER 45 DEG. CROSSWIND FLAPS DOWN	HOVER 90 DEG CROSSWIND FLAPS DOWN	FWD. FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT
- TRIM CHARACTERISTICS							
True Airspeed, kt	35.0	35.0	35.0	40.0	40.0	80.0	80.0
Pitch Angle, deg	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bank Angle, deg	0.0	-4.67	-9.13	0.0	0.0	0.0	0.0
Angle of Attack, deg	0.0	-4.65	-90.11	0.0	0.0	0.0	0.0
Sideslip Angle, deg	0.0	-44.84	-80.87	0.0	0.0	0.0	0.0
Total Thrust, lb	30820	31149	31619	30892	43587	33009	45578
Nozzle Deflection, deg	87.38	87.86	90.29	87.78	87.32	80.76	82.44
Pitch Trim Moment Appl. by Propulsion System, ft-lb	-4018	-5285	-4923	-4613	-5390	-7208	-9667
Trim Roll Moment Appl. by RCS, ft-lb	0.0	-1927	-2406	0.0	0.0	0.0	0.0
Yaw Thrust Defl, deg	0.0	1.47	2.66	0.0	0.0	0.0	0.0
Wing TE Flap Defl, deg	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Canard Incidence, deg	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table B.4.1 Trim and Modal Characteristics of RALS Airplane (Continued)

PARAMETER \ FLIGHT CONDITION	HOVER HEADWIND FLAPS DOWN	HOVER 45 DEG. CROSSWIND FLAPS DOWN	HOVER 90 DEG CROSSWIND FLAPS DOWN	FWD. FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT
- MODAL CHARACTERISTICS*							
Longitudinal	[0.0900, 0.214; -0.387, 0.232] (-0.287) (-0.111)	[0.0840, 0.188; -0.408, 0.206] (-0.242) (-0.0934)	[-0.0456, 0.0828; 0.483, 0.0946] (0.0854) (-0.0739)	[0.143, 0.171, -0.641,0.223] (-0.402) (-0.122)	[0.159,0.145 -0.737, 0.215] (-0.449) (-0.0661)	(-0.569) (-0.120) (0.0684) (0.203)	(-0.613) (-0.116) (0.119) (0.273)
Lateral	[0.205,0.462 -0.405, 0.505] (-0.614) (-0.0419)	[0.186, 0.430; -0.396, 0.469] (-0.572) (-0.0709)	[0.216, 0.468; -0.420,0.515] (-0.606) (-0.0793)	[0.221,0.451; -0.440,0.502] (-0.672) (-0.0453)	[0.229,0.411 -0.486, 0.471] (-0.647) (-0.0569)	[0.220,0.558 -0.367, 0.600] (-0.895) (-0.0579)	[0.238,0.500 -0.429, 0.554] (-0.851) (-0.0722)

*$[-\zeta\omega_n, \omega_n\sqrt{1-\zeta^2}; \zeta, \omega_n]$ indicates complex root pair located at $s = -\zeta\omega_n \pm j\omega_n\sqrt{1-\zeta^2}$ with natural frequency of ω_n rad/sec and damping ratio of ζ

(λ) indicates real root located at $s = \lambda$

Table B.4.1 Trim and Modal Characteristics of RALS Airplane (Continued)

DERIVATIVE \ FLIGHT CONDITION	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT.	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLT. 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLT. 1.4 V_s FLAPS UP FLT. DES. WGT.
- TRIM CHARACTERISTICS						
True Airspeed, kt	120.0	120.0	120.0	160.0	200.0	197.4
Pitch Angle, deg	0.0	0.0	4.0	4.0	8.51	11.19
Bank Angle, deg	0.0	0.0	0.0	0.0	0.0	0.0
Angle of Attack, deg	0.0	0.0	4.0	4.0	8.51	11.19
Sideslip Angle, deg	0.0	0.0	0.0	0.0	0.0	0.0
Total Thrust, lb	35736	48751	30186	27164	4039	5965
Nozzle Deflection, deg	73.76	76.50	67.76	58.69	0.0	0.0
Pitch Trim Moment Appl. by Propulsion System, ft-lb	-3103	-8388	3294	29187	0.0	0.0
Trim Roll Moment Appl. by RCS, ft-lb	0.0	0.0	0.0	0.0	0.0	0.0
Yaw Thrust Defl, deg	0.0	0.0	0.0	0.0	0.0	0.0
Wing TE Flap Defl, deg	20.0	20.0	20.0	20.0	- 5.27	- 2.80
Canard Incidence, deg	0.0	0.0	0.370	0.370	2.04	3.81

Table B.4.1 Trim and Modal Characteristics of RALS Airplane (Concluded)

DERIVATIVE / FLIGHT CONDITION	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT.	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLT. 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLT. 1.4 V_s FLAPS UP FLT. DES. WGT.
- MODAL CHARACTERISTICS						
Longitudinal	[-0.0947, 0.141; 0.557,0.170] (-0.763) (0.368)	[-0.0539,0.0617; 0.658,0.0819] (-0.799) (0.434)	[-0.342,0.612; 0.488,0.701] (0.172) (-0.194)	[-0.446,0.897; 0.445,1.001] (0.210) (-0.209)	[-0.558,1.200; 0.422,1.323] [-0.00509, 0.115; 0.0444,0.115]	[-0.420,0.840; 0.447,0.939] [-0.00502, 0.120; 0.0418,0.120]
Lateral	[0.200, 0.648; -0.295,0.678] (-1.082) (-0.0673)	[0.225,0.572; -0.367,0.615] (-1.016) (-0.0856)	[0.165,0.780; -0.207,0.797] (-1.022) (-0.0600)	[0.0946,0.934; -0.101,0.939] (-1.120) (-0.0555)	[-0.137,1.417; 0.0964,1.423] (-0.910) (-0.0225)	[-0.193, 1.549; 0.124,1.561] (-0.758) (-0.0257)

Table B.4.2 Longitudinal Stability Derivatives of RALS Airplane

DERIVATIVE \ FLIGHT CONDITION	HOVER 35 KT HEADWIND FLAPS DOWN	HOVER 35 KT 45 DEG CROSSWIND FLAPS DOWN	HOVER 35 KT 90 DEG CROSSWIND FLAPS DOWN	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT
- X-DERIVATIVES							
X_u - $ft/sec^2/ft/sec$	-0.0380	-0.0308	-0.0138	-0.0415	-0.0329	-0.0644	-0.0509
X_w - $ft/sec^2/ft/sec$	0.00151	-0.00385	-0.00044	0.00177	0.00125	0.00374	0.00264
X_q - $ft/sec^2/rad/sec$	0.00477	-0.0176	0.0198	0.00600	0.00317	0.0157	0.0100
$X_{\delta_{ELEVON}}$ - $ft/sec^2/rad$	-0.136	-0.0813	0.0	-0.177	-0.125	-0.708	-0.501
$X_{BT_{PITCH}}$ - $ft/sec^2/lb$	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$X_{\delta_{NOZ}}$ - $ft/sec^2/rad$	-31.96	-32.30	-32.75	-32.04	-31.98	-34.36	-33.49
X_{BT} - $ft/sec^2/lb$	0.00010	0.00011	0.0	0.00013	0.00007	0.00044	0.00024
- Z-DERIVATIVES							
Z_u - $ft/sec^2/ft/sec$	-0.00317	0.00220	-0.00044	0.0163	-0.00670	0.0309	0.0256
Z_w - $ft/sec^2/ft/sec$	-0.118	-0.0856	-0.0442	-0.131	-0.0966	-0.238	-0.172
Z_q - $ft/sec^2/rad/sec$	0.0178	0.0453	0.155	-0.00177	0.0477	-0.150	-0.0575
$Z_{\delta_{ELEVON}}$ - $ft/sec^2/rad$	-0.791	-0.392	0.0	-1.034	-0.731	-4.134	-2.925
$Z_{BT_{PITCH}}$ - $ft/sec^2/lb$	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$Z_{\delta_{NOZ}}$ - $ft/sec^2/rad$	-1.463	-1.204	0.160	-1.792	-1.496	-5.026	-4.150
Z_{BT} - $ft/sec^2/lb$	-0.00420	-0.00419	-0.00416	-0.00430	-0.00296	-0.00427	-0.00305

Table B.4.2 Longitudinal Stability Derivatives of RALS airplane (Continued)

DERIVATIVE \ FLIGHT CONDITION	HOVER 35 KT HEADWIND FLAPS DOWN	HOVER 35 KT 45 DEG CROSSWIND FLAPS DOWN	HOVER 35 KT 90 DEG CROSSWIND FLAPS DOWN	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT
- M-DERIVATIVES							
M_u - rad/sec^2/ft/sec	0.00048	0.00032	-0.00002	0.00045	0.00054	-0.00003	0.00018
M_w - rad/sec^2/ft/sec	0.00103	0.00111	0.00186	0.00101	0.00148	0.00116	0.00161
M_q - rad/sec^2/rad/sec	-0.0627	-0.0513	-0.0216	-0.0692	-0.0716	-0.122	-0.122
$M_{\delta_{ELEVON}}$ - rad/sec^2/rad	-0.0598	-0.0298	0.0	-0.0780	-0.0735	-0.312	-0.294
$M_{\Delta T_{PITCH}}$ - rad/sec^2/lb	0.00051	0.00051	0.00051	0.00051	0.00050	0.00051	0.00052
$M_{\delta_{NOZ}}$ - rad/sec^2/rad	-0.392	-0.397	-0.412	-0.390	-0.522	-0.382	-0.513
$M_{\Delta T}$ - rad/sec^2/lb	0.00013	0.00013	0.00013	0.00013	0.00011	0.00012	0.00011

Table B.4.2 Longitudinal Stability Derivatives of RALS Airplane (Continued)

PARAMETER \ FLIGHT CONDITION	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT.	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 1.4 V_s FLAPS UP FLT. DES. WGT.
- X-DERIVATIVES						
X_u - ft/sec^2/ft/sec	-0.0751	-0.0622	-0.0692	-0.0512	-0.00864	-0.00704
X_w - ft/sec^2/ft/sec	0.00569	0.00403	0.0253	0.0362	0.0913	0.0915
X_q - ft/sec^2/rad/sec	0.0252	0.0168	0.102	0.137	0.378	0.331
$X_{\delta_{ELEVON}}$ - ft/sec^2/rad	-1.592	-1.127	-1.443	-2.566	4.383	3.491
$X_{\Delta T_{PITCH}}$ - ft/sec^2/lb	0.0	0.0	0.0	0.0	-0.00183	-0.00140
$X_{\delta_{NOZ}}$ - ft/sec^2/rad	-37.61	-36.05	-31.78	-29.40	0.0	-0.517
$X_{\Delta T}$ - ft/sec^2/lb	0.00073	0.00042	0.00108	0.00108	0.00183	0.00140
- Z-DERIVATIVES						
Z_u - ft/sec^2/ft/sec	0.0239	0.0240	-0.0107	-0.0434	-0.0681	-0.0798
Z_w - ft/sec^2/ft/sec	-0.344	-0.248	-0.439	-0.581	-0.806	-0.571
Z_q - ft/sec^2/rad/sec	-0.294	-0.158	-0.953	-1.342	-2.195	-1.480
$Z_{\delta_{ELEVON}}$ - ft/sec^2/rad	-9.302	-6.582	-9.318	-16.57	-25.30	-18.46
$Z_{\Delta T_{PITCH}}$ - ft/sec^2/lb	0.0	0.0	0.0	0.0	-0.00005	-0.00004
$Z_{\delta_{NOZ}}$ - ft/sec^2/rad	-8.531	-7.233	-9.637	-10.37	-4.19	-4.06
$Z_{\Delta T}$ - ft/sec^2/lb	-0.00399	-0.00293	-0.00383	-0.00304	-0.00005	-0.00004

Table B.4.2 Longitudinal Stability Derivatives of RALS Airplane (Concluded)

PARAMETER \ FLIGHT CONDITION	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT.	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 1.4 V_s FLAPS UP FLT. DES. WGT.
- M-DERIVATIVES						
M_u - rad/sec^2/ft/sec	-0.00083	-0.00047	-0.00118	-0.00256	0.00052	0.00040
M_w - rad/sec^2/ft/sec	0.00136	0.00182	-0.00175	-0.00298	-0.00441	-0.00216
M_q - rad/sec^2/rad/sec	-0.176	-0.172	-0.214	-0.278	-0.336	-0.287
$M_{\delta_{ELEVON}}$ - rad/sec^2/rad	-0.702	-0.662	-0.713	-1.268	-1.909	-1.826
$M_{\delta T_{PITCH}}$ - rad/sec^2/lb	0.00051	0.00050	0.00049	0.00039	0.0	0.0
$M_{\delta_{NOZ}}$ - rad/sec^2/rad	-0.348	-0.488	-0.242	-0.385	-0.385	-0.533
$M_{\Delta T}$ - rad/sec^2/lb	0.00011	0.00011	0.00011	0.00009	0.0	0.0

TABLE B.4.3 Lateral Stability Derivatives of RALS Airplane

DERIVATIVE \ FLIGHT CONDITION	HOVER 35 KT HEADWIND FLAPS DOWN	HOVER 35 KT 45 DEG CROSSWIND FLAPS DOWN	HOVER 35 KT 90 DEG CROSSWIND FLAPS DOWN	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT
- Y-DERIVATIVES							
Y_v - ft/sec^2/ft/sec	-0.0324	-0.108	-0.152	-0.0349	-0.0287	-0.0555	-0.0433
Y_p - ft/sec^2/rad/sec	-0.0792	-0.0648	-0.0830	-0.0909	-0.0632	-0.184	-0.129
Y_r - ft/sec^2/rad/sec	0.0199	-0.0170	0.0212	0.0455	-0.0167	0.242	0.123
Y_{δ_A} - ft/sec^2/rad	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$Y_{RCS\,ROLL}$ - ft/sec^2/lb	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Y_{δ_R} - ft/sec^2/rad	0.307	0.0686	0.0	0.401	0.284	1.604	1.136
$Y_{\delta_{YAW}}$ - ft/sec^2/rad	6.955	7.064	7.009	7.039	6.957	7.981	7.695
- L-DERIVATIVES							
L_v - rad/sec^2/ft/sec	-0.00463	-0.00275	-0.00360	-0.00528	-0.00445	-0.0104	-0.00884
L_p - rad/sec^2/ft/sec	-0.183	-0.135	-0.0657	-0.208	-0.182	-0.407	-0.353
L_r - rad/sec^2/rad/sec	0.0810	0.0503	0.0555	0.0920	0.0797	0.180	0.155
L_{δ_A} - rad/sec^2/rad	-0.341	-0.169	0.0	-0.446	-0.382	-1.783	-1.528
$L_{RCS\,ROLL}$ - rad/sec^2/lb	0.00156	0.00156	0.00156	0.00156	0.00134	0.00156	0.00134
L_{δ_R} - rad/sec^2/rad	0.0847	0.0189	0.0	0.111	0.0951	0.442	0.380
$L_{\delta_{YAW}}$ - rad/sec^2/rad	0.239	0.227	0.190	0.247	0.292	0.367	0.398

Table B.4.3 Lateral Stability Derivatives of RALS Airplane (Continued)

DERIVATIVE \ FLIGHT CONDITION	HOVER 35 KT HEADWIND FLAPS DOWN	HOVER 35 KT 45 DEG CROSSWIND FLAPS DOWN	HOVER 35 KT 90 DEG CROSSWIND FLAPS DOWN	FWD. FLIGHT LEVEL ATT. 40 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 40 KT FLAPS DOWN TAKEOFF WGT	FWD. FLIGHT LEVEL ATT. 80 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 80 KT FLAPS DOWN TAKEOFF WGT.
- N-DERIVATIVES							
N_v - rad/sec^2/ft/sec	-0.00058	-0.00374	-0.00466	-0.00050	-0.00094	0.00005	-0.00043
N_p - rad/sec^2/rad/sec	0.00691	0.00772	0.00852	0.00784	0.00741	0.0153	0.0143
N_r - rad/sec^2/rad/sec	-0.0334	-0.0314	-0.0383	-0.0358	-0.0395	-0.0559	-0.0581
N_{δ_A} - rad/sec^2/rad	0.00825	0.00489	0.0	0.0108	0.0100	0.0431	0.0400
$N_{RCS_{ROLL}}$ - rad/sec^2/lb	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N_{δ_R} - rad/sec^2/rad	-0.0253	-0.00656	0.0	-0.0330	-0.0306	-0.132	-0.122
$N_{\delta_{YAW}}$ - rad/sec^2/rad	-3.606	-3.642	-3.698	-3.613	-4.737	-3.847	-4.938

Table B.4.3 Lateral Stability Derivatives of RALS Airplane (Continued)

PARAMETER \ FLIGHT CONDITION	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT.	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 1.4 V_s FLAPS UP FLT. DES. WGT.
- Y-DERIVATIVES						
Y_v - ft/sec^{2}ft/sec	-0.0764	-0.0582	-0.0733	-0.0913	-0.0993	-0.0739
Y_p - ft/sec^2/rad/sec	-0.277	-0.195	-0.277	-0.371	-0.463	-0.344
Y_r - ft/sec^2/rad/sec	0.435	0.258	0.464	0.688	1.013	0.745
Y_{δ_A} - ft/sec^2/rad	0.0	0.0	0.0	0.0	0.0	0.0
$Y_{RCS\,ROLL}$ - ft/sec^2/1g	0.0	0.0	0.0	0.0	0.0	0.0
Y_{δ_R} - ft/sec^2/rad	3.608	2.556	3.608	6.415	10.02	7.178
$Y_{\delta_{YAW}}$ - ft/sec^2/rad	8.812	8.504	7.419	5.524	4.192	4.706
- L-DERIVATIVES						
L_v - rad/sec^2/ft/sec	-0.0155	-0.0132	-0.0195	-0.0259	-0.0335	-0.0362
L_p - rad/sec^2/rad/sec	-0.607	-0.524	-0.616	-0.818	-1.028	-1.019
L_r - rad/sec^2/rad/sec	0.269	0.231	0.352	0.468	0.551	0.614
L_{δ_A} - rad/sec^2/rad	-4.012	-3.438	-4.014	-7.137	-10.93	-10.35
$L_{RCS\,ROLL}$ - rad/sec^2/1b	0.00156	0.00134	0.00156	0.00156	0.0	0.0
L_{δ_R} - rad/sec^2/rad	0.995	0.855	0.859	1.527	1.856	1.565
$L_{\delta_{YAW}}$ - rad/sec^2/rad	0.561	0.575	0.601	0.786	-0.273	-0.396

TABLE B.4.3 Lateral Stability Derivatives of RALS Airplane (Concluded)

PARAMETER \ FLIGHT CONDITION	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT LEVEL ATT. 120 KT FLAPS DOWN TAKEOFF WGT.	FWD. FLIGHT 4 DEG. ATT. 120 KT FLAPS DOWN LAND. WGT.	FWD. FLIGHT 4 DEG. ATT. 160 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 200 KT FLAPS DOWN LAND. WGT.	CRUISE LEVEL FLIGHT 1.4 V_s FLAPS UP FLT. DES. WGT.
- N DERIVATIVES						
N_v - rad/sec^2/ft/sec	0.00056	0.00003	0.00069	0.00141	0.00275	0.00231
N_p - rad/sec^2/rad/sec	0.0227	0.0212	0.0167	0.0221	0.0173	0.00991
N_r - rad/sec^2/rad/sec	-0.0762	-0.0772	-0.0744	-0.0921	-0.0936	-0.0912
N_{δ_A} - rad/sec^2/rad	0.0969	0.0900	0.0890	0.158	-0.260	-0.262
$N_{RCS\,ROLL}$ - rad/sec^2/lb	0.0	0.0	0.0	0.0	0.0	0.0
N_{δ_R} - rad/sec^2/rad	-0.297	-0.275	-0.250	-0.444	-0.590	-0.519
$N_{\delta_{YAW}}$ - rad/sec^2/rad	-4.156	-5.268	-3.505	-3.172	-0.355	-0.510

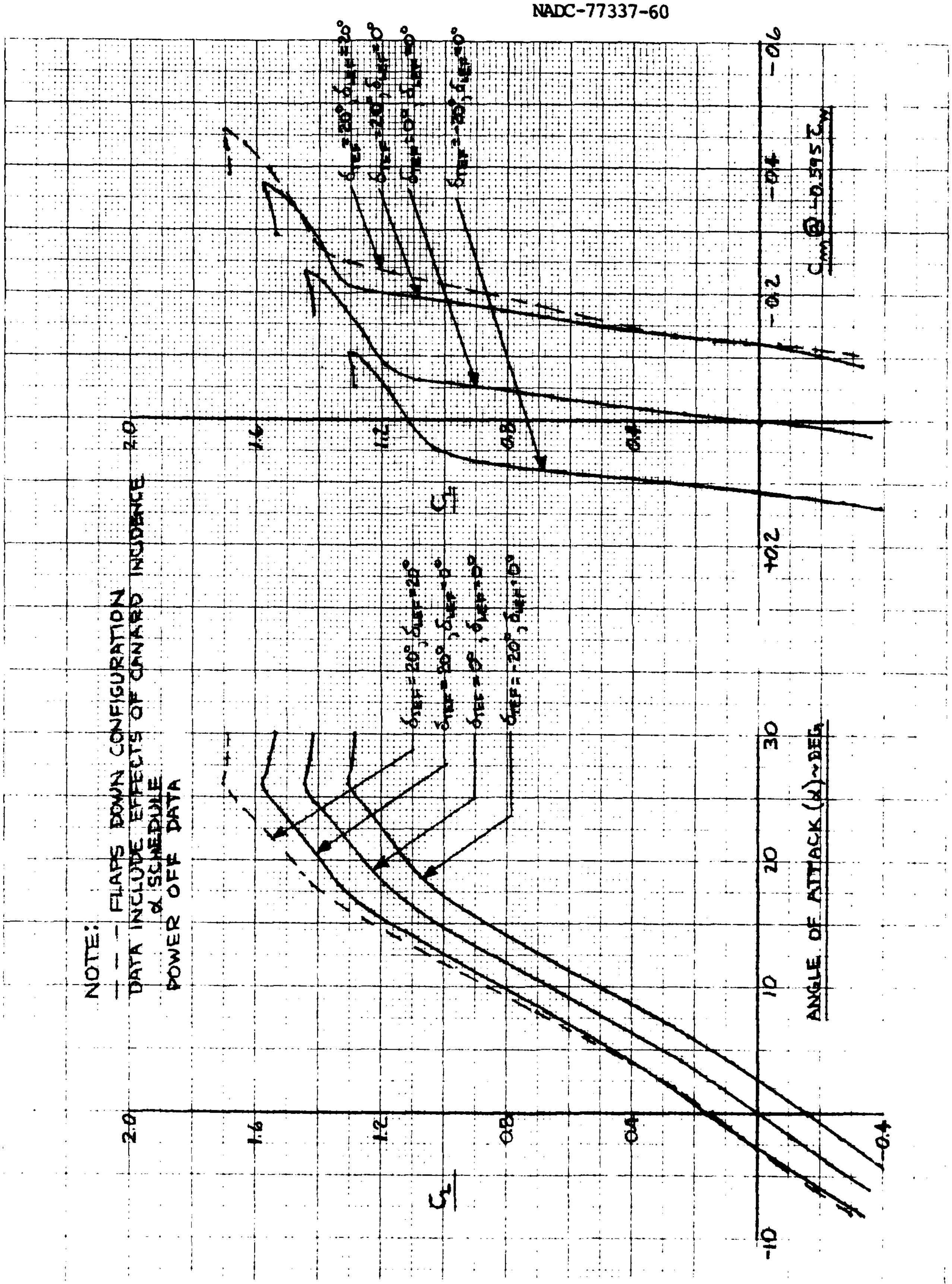


Figure B.4.1 - RALS Low Angle of Attack ($0 \leq \alpha \leq 30$ deg) Power Off Longitudinal Aerodynamic Characteristics

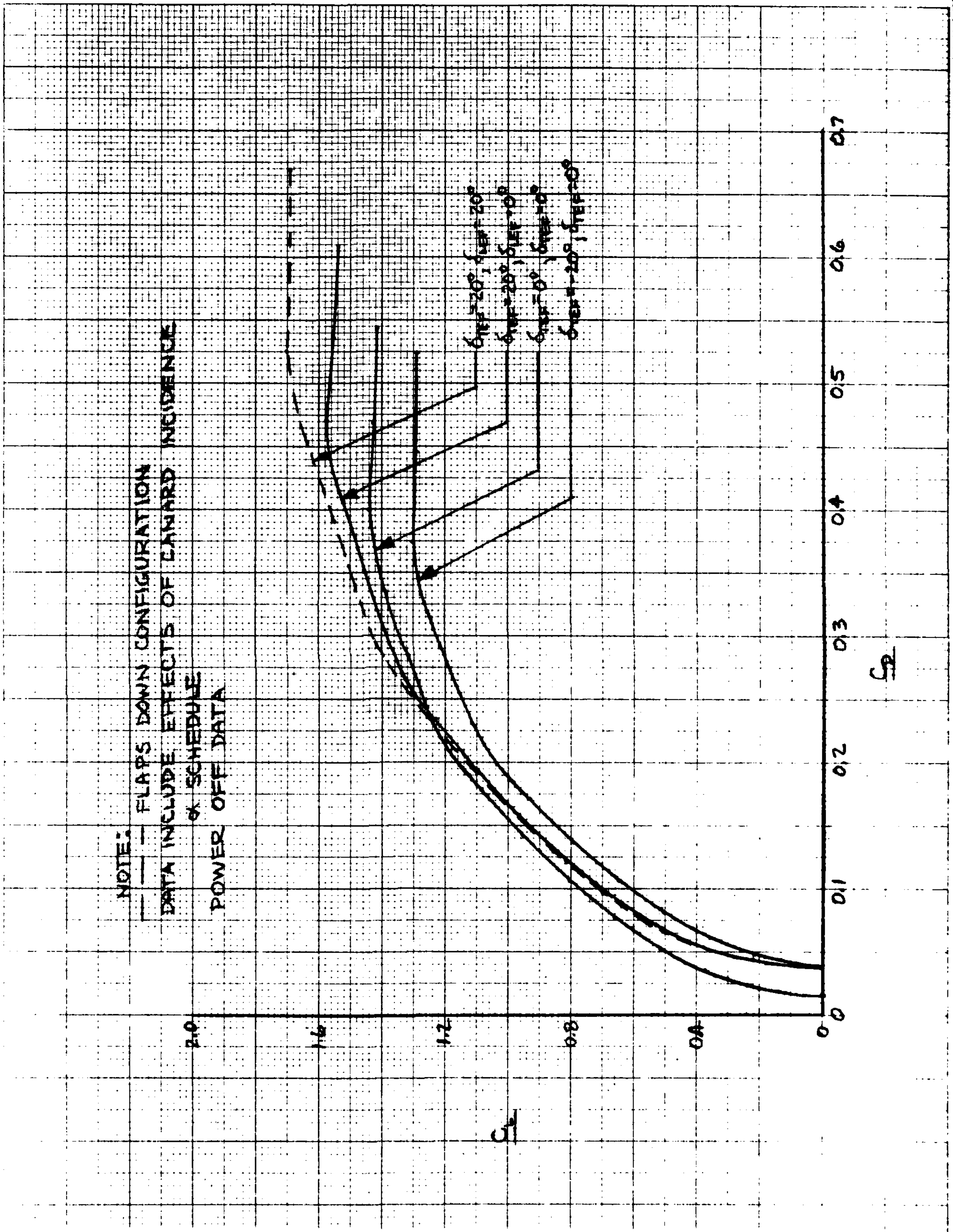


Figure B.4.1 (Cont.) - RALS Low Angle of Attack ($0 \leq \alpha \leq 30$ deg) Power Off Longitudinal Aerodynamic Characteristics

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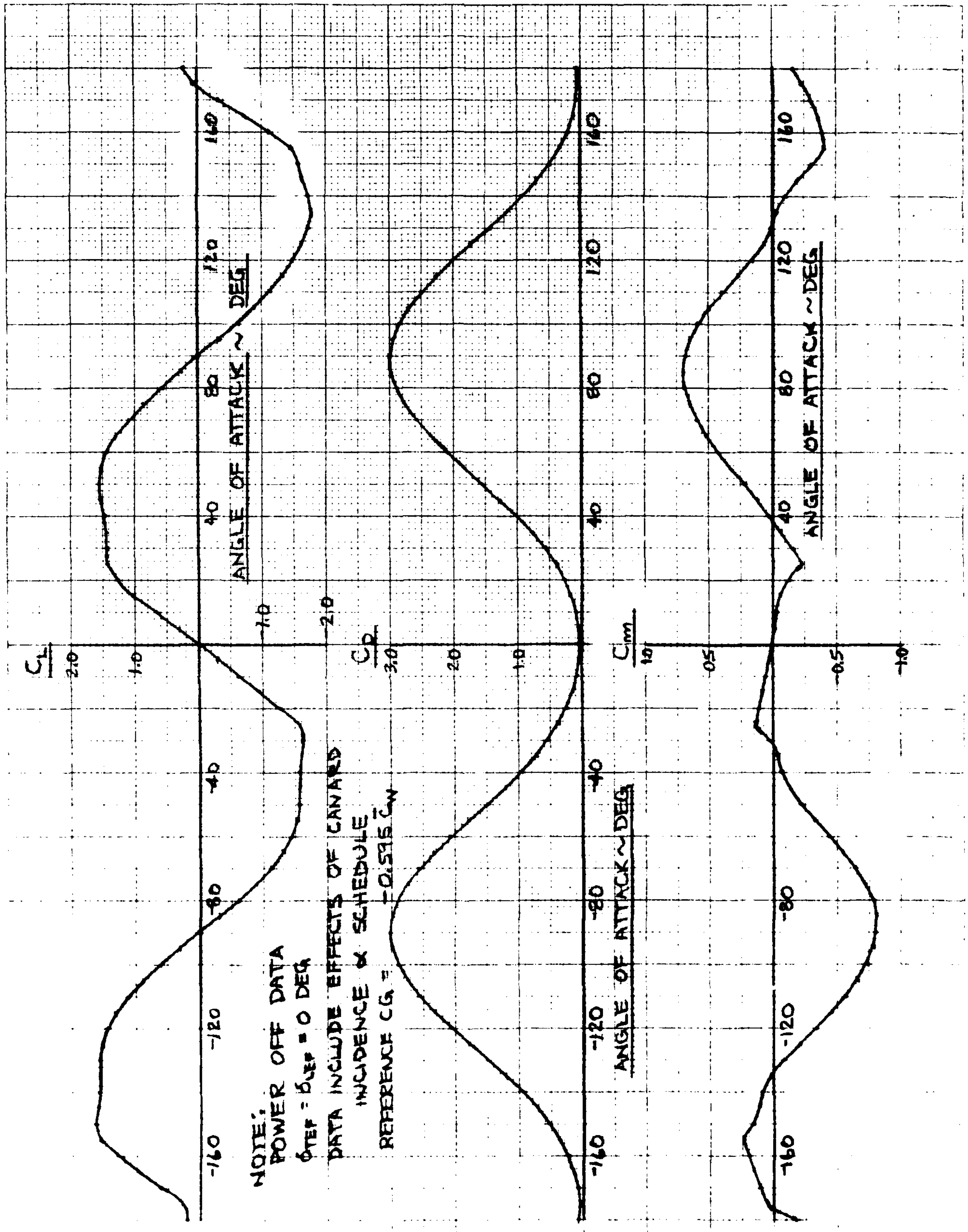

Figure B.4.2 - RALS High Angle of Attack (to ± 180 deg) Power Off Longitudinal Aerodynamic Characteristics

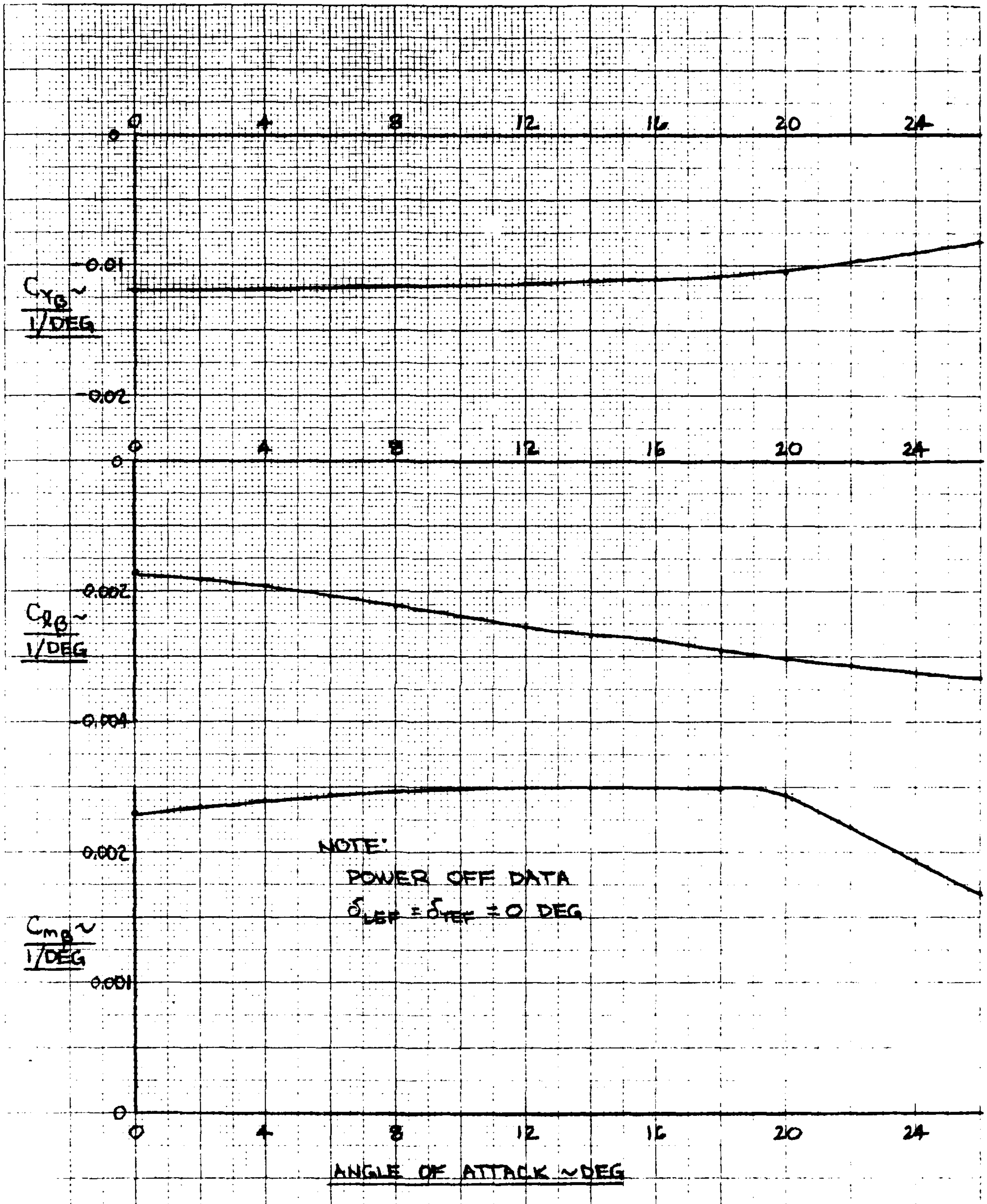

Figure B.4.3 - RALS Low Angle of Attack ($0 \leq \alpha \leq 30$ deg) Power Off Static Lateral Directional Derivatives

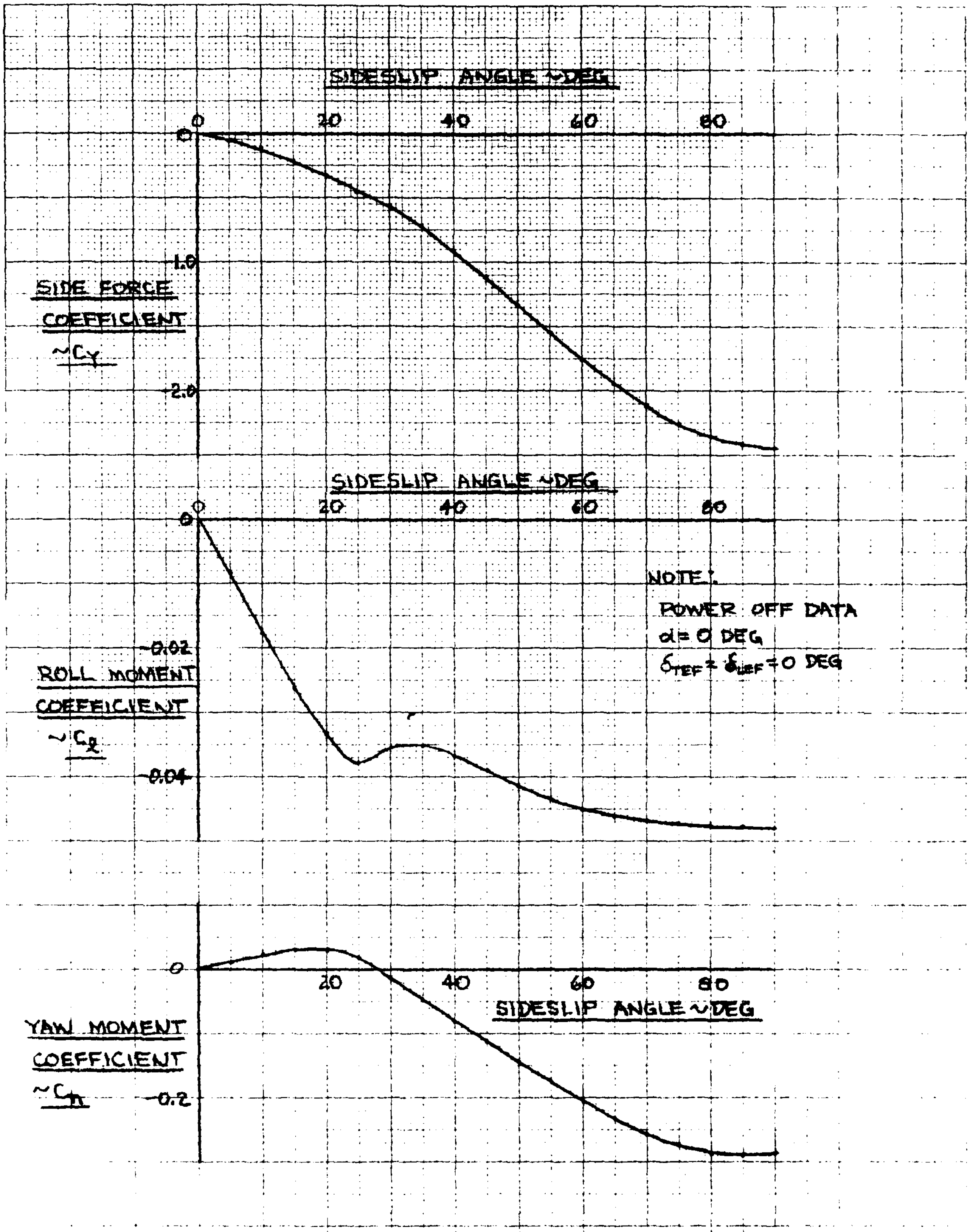

Figure B.4.4 - RALS Power Off Lateral Directional Aerodynamic Characteristics at Large Sideslip Angles (0 to 90 deg)

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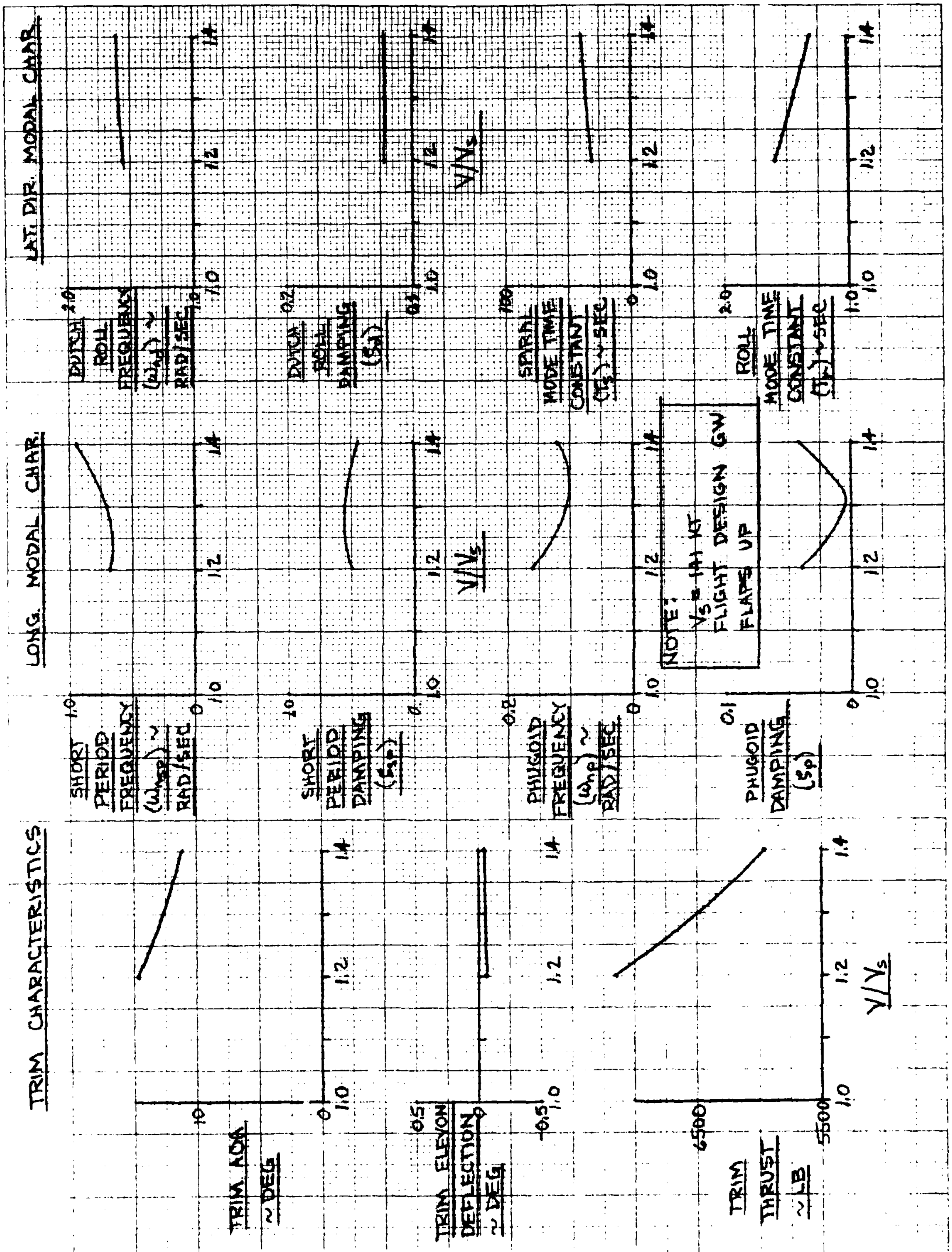

Figure B.4.5 - RALS Cruise Trim Summary

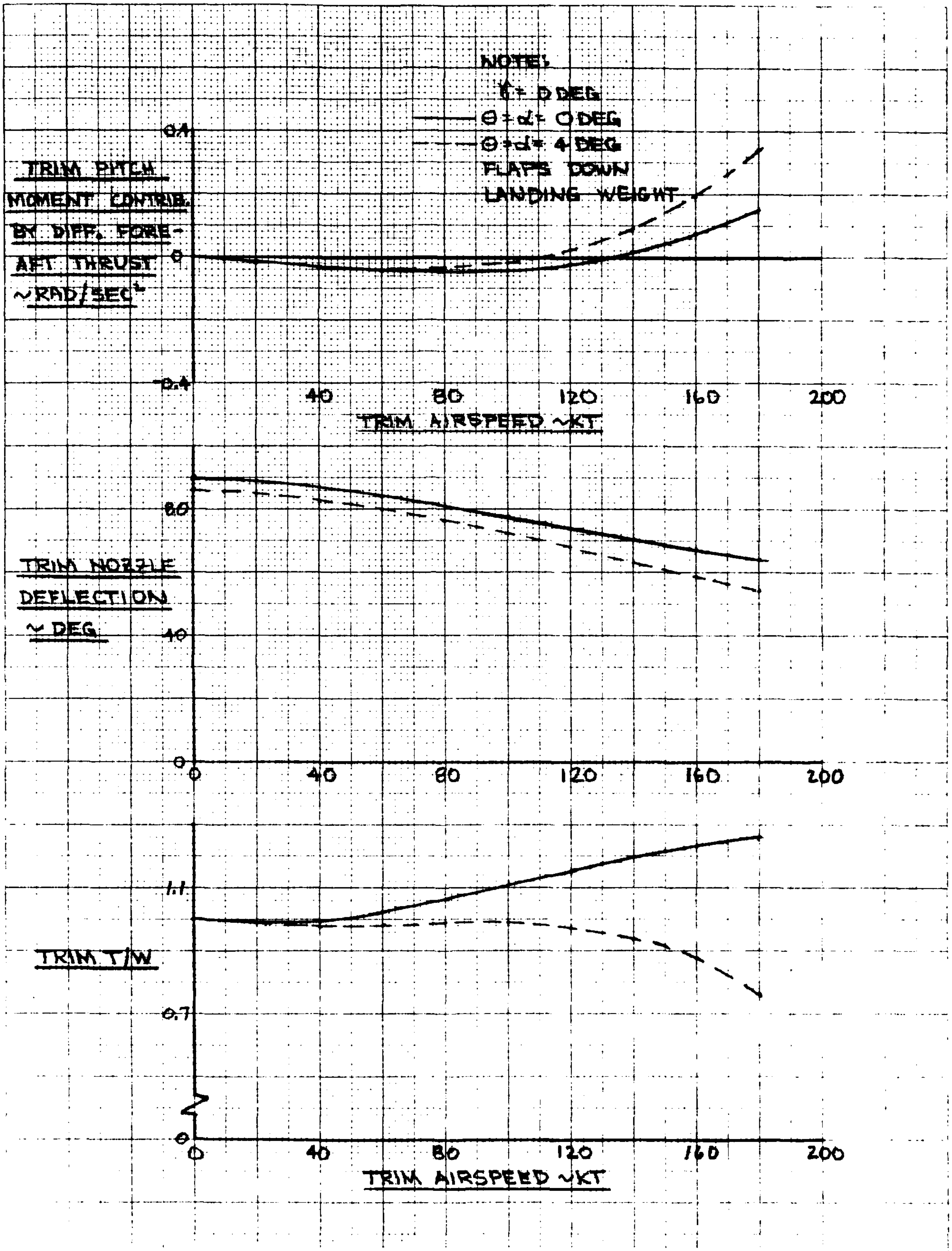

Figure B.4.6 - RALS Forward Flight Trim Summary

B.5 References

B-a Fortenbaugh, R. L, A Mathematical Model for Vertical Attitude Take-Off and Landing (VATOL) Aircraft Simulation, (In preparation).

B-b Clark, Jr., J. W., Low-Speed V/STOL Stability and Control Prediction - Volume I: Model Description and Validation, NADC Report NADC-76312-30, 11 January 1977.

B-c Williams, J. E. and Vukelich, S. R., The USAF Stability and Control Digital DATCOM, Volume I, Users Manual, AFFDL-TR-76-45, November 1976.

B-d Sherrieb, H.E., A Low Speed Wind Tunnel Test of V/STOL Type A Fan Powered Model 3-6 in the 7 x 10 ft Section, Vought Report 2-53300/7R-51445, 1977.

B-e Litchfield, A. F., VSTOL Type A Jet Induced Interference Effects in Transition-Forward Jets, 4 Poster Configuration, Vought Report 2-53300/7AVO-177, 4 May 1977.

B-f Sherrieb, H. E., Propulsion Induced Aerodynamic Effects Estimated for Design Sensitivity to Flying Qualities Study, Vought Report 2-32400/0AVO-4, 21 January 1980.

APPENDIX C
DESCRIPTION OF THE ASAP COMPUTER ROUTINE

The Aircraft Synthesis Analysis Program (ASAP) is a Vought proprietary computer model for conducting aircraft design and performance studies which include sizing, costing, and optimization. ASAP combines various engineering disciplines under one computer system, automates a significant portion of the advanced design process (i.e., initiation, analysis and optimization), and provides a system applicable to the entire advanced design acquisition cycle.

Figure C-1 shows ASAP to be a collection of computer modules which represent basic components of the design process (i.e., Initiation, Analysis, Optimization) and man machine interface, plus the executive routine that controls all activities. Each analysis module was developed and is maintained by the cognizant technology discipline and contains that methodology normally utilized in day to day advanced design activities by that discipline. Each module is a complete computer routine made up of many subroutines, (e.g. the Weights Module consists of in excess of one hundred subroutines, the Performance Module in excess of eighty, etc.). Analysis capabilities range from simple statistical and empirical relationships to detailed analytical techniques. Provisions are included to allow direct input of data generated external to the progrm (e.g., wind tunnel data, NASTRAN results, etc.).

Modular construction allows ASAP to be flexible in nature so that subroutine modules can be added, deleted, and/or revised without disrupting the entire program. The program remains useful over a long period of time because it can be modified to account for advancing technology, emerging disciplines, new analysis techniques, and a wider spectrum of aircraft systems.

ASAP is designed to operate as a complete synthesis program or in one of three partial modes as illustrated in Figure C-2. The "partial" synthesis modes are designed to permit program use as a separate parametric analysis program or as a separate analysis program with or without an Initiation Module. These modes of operation are necessary because advanced design studies vary in scope (from simple vehicle analyses, to complex parametric analyses, to complete system optimization) and starting point (from a conceptual idea in a designer's mind to an existing three-view layout).

Figure C-3 depicts the three basic operational phases of ASAP: aircraft balancing, aircraft sizing, and aircraft optimization and initiation. The balancing phase determines takeoff gross weight and cost for "fuel-balanced" aircraft which satisfy a user defined mission, or, determines the mission segment value and cost for "mission balanced" aircraft which satisfy a user defined takeoff gross weight. The sizing phase combines three "balanced" aircraft which uses defined operational requirements (constraints such as V_{max}, acceleration time, takeoff distance, etc.) to determine characteristics of aircraft that satisfy both mission and operational requirements. Optimization incorporates logic designed to exercise elements from the aircraft sizing phase to define the "optimum" configuration; initiation includes a logic to allow ASAP to be run with very limited inputs (i.e., those normally available in customer type specs, study spec, etc.). Formulation of the program began in mid-1969; development and checkout of the individual computer routines required for the "prototype" program (ASAP-1) was completed in December 1969. ASAP-2, representing complete automation of the Analysis phase, became operational in mid-1971. The optimization module became operational in 1972, and the initiation module followed in 1973. ASAP development is "open ended" allowing it to accept emerging disciplines and new analysis techniques, and to accept data banks which extend its applicability to a wider spectrum of vehicles.

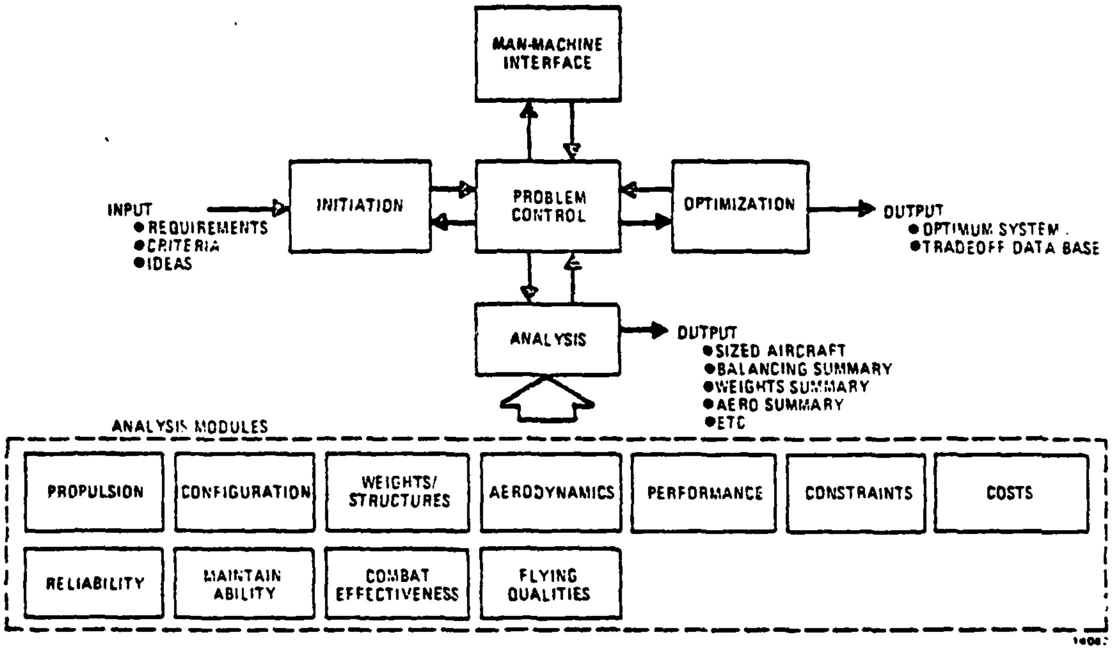

Figure C-1. ASAP is an Interdisciplinary Computer System Combining the Three Fundamental Tasks of Design Synthesis - Initiation, Analysis and Optimization.

Vought uses ASAP to investigate interactions among configuration design requirements, configuration variables and resource criteria. Significant interaction effects are demonstrated by the influence of aircraft geometry, engine cycle, avionics suite, weapon carriage mode, materials mix, mission requirements, operational and performance requirements, wing loading and thrust loading on aircraft weight, size, cost and effectiveness. Accuracy has been validated by successful "after the fact" synthesis of real aircraft. ASAP accelerates the design evaluation process, provides large quantities of data for aircraft parameter selection at minimum cost, properly interfaces technical functions among various engineering disciplines, and provides automatic documentation of engineering decisions, analyses and results.

ASAP was selected by NAVAIR for installation on Navy computers and is currently operational at DTNSRDC.

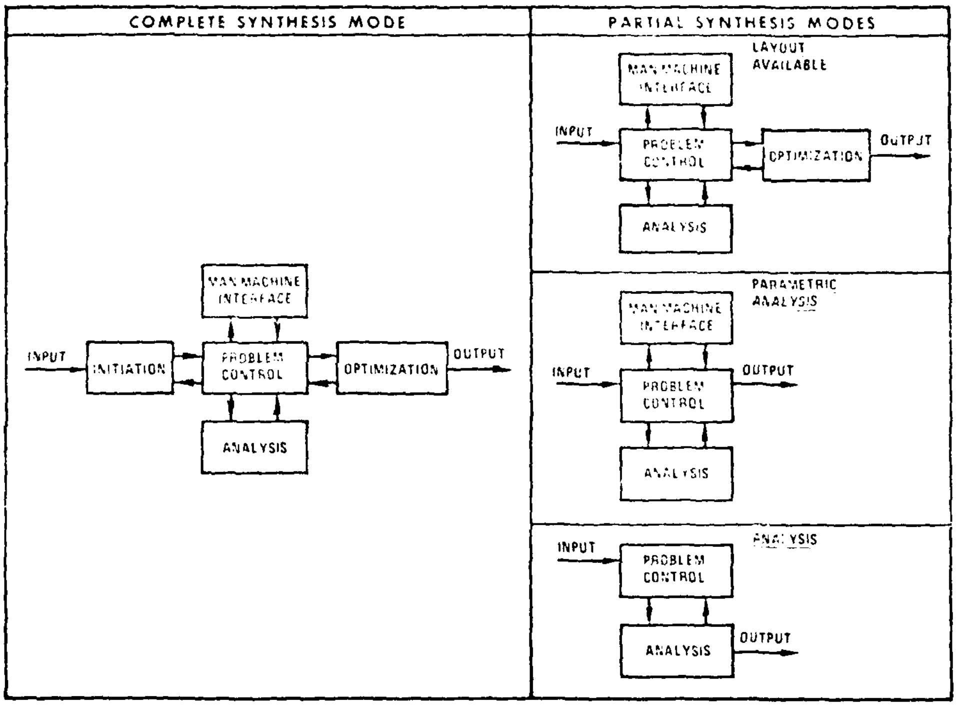

Figure C-2. ASAP Flexibility Permits the User to Tailor the Tool to the Problem

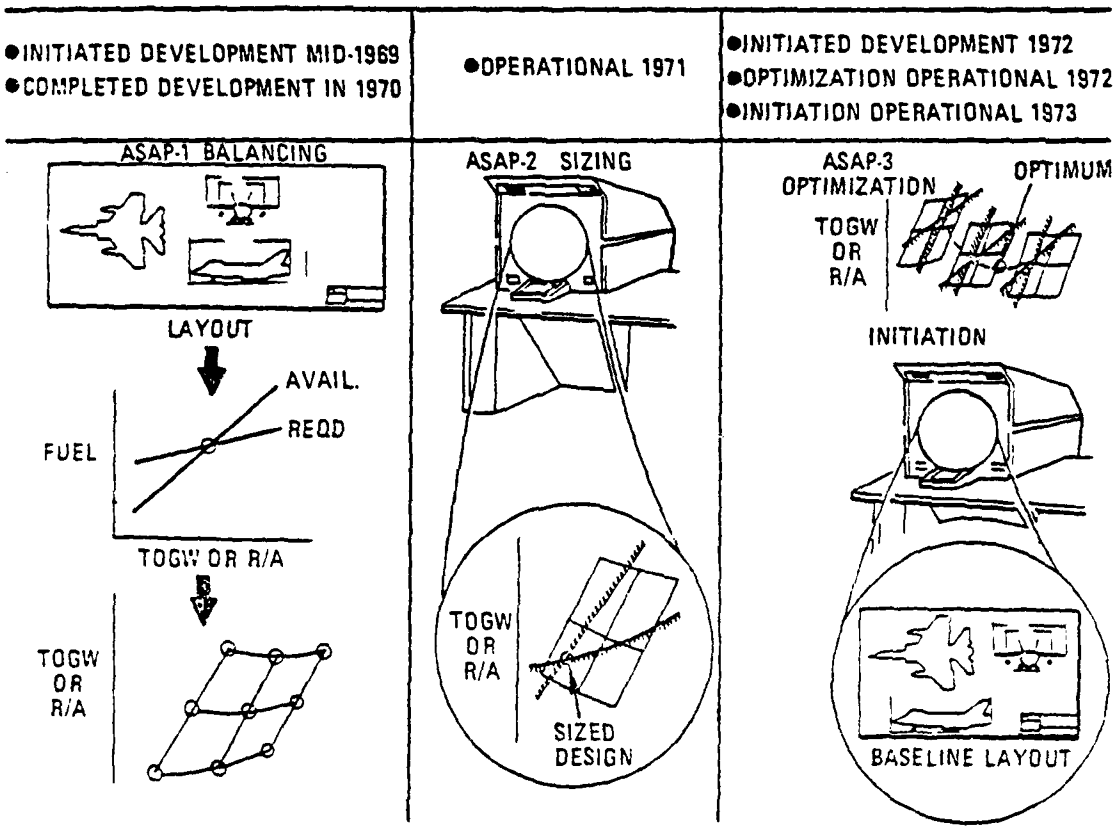

Figure C-3. ASAP Has Been A Continuing Development Effort at Vought Since 1969 and is Currently Being Installed on NAVAIR Computers.

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APPENDIX D
DESCRIPTION OF THE OLSIM COMPUTER ROUTINE

D.1 OLSIM

OLSIM is a multi-purpose digital computer program which is used for stability and control analysis and flight control system design analysis in addition to off-line flight simulation. It provides a flexible framework and standardized modules which facilitate the development of off-line aircraft simulations. OLSIM runs under the control of VTOLTH, the main program, which calls the proper modules for executing user-specified options. These options include trim, stability derivative calculation, time history generation, and various input-output options. Standardized modules include TRIM which has a six DOF nonlinear trim capabilty, RUNGE which performs 4th order Runge-Kutta integration, and various table lookup and matrix computation routines. User supplied aircraft specific modules include FORCES for calculating forces and moments on the airplane, SYSEQS for control system equations and aircraft kinematics, and DERIVS which perturbs the aircraft about trim to generate stability derivatives.

The aerodynamic model programmed in OLSIM is a modified version of the aerodynamic model described in reference D1. It calculates aerodynamic foce and moment coefficients using DATCOM-type relations for all angles of attack and sideslip. To review the aerodynamic coefficients generated by this model, a special wind tunnel option is included in OLSIM. This option provides for the calculation of nondimensional aerodynamic coefficients as functions of angle of attack and sideslip.

D.2 OLSIM PROGRAM MODULES

D.2.1 The Main Program

VTOLTH is the main program module for OLSIM. It controls most of the input and output and all the calculations of the program based upon sequences of program options selected by the user from a group of twelve which are currently available. These options provide for loading or reading data in the COMMON array, specifying trim variables or variables for stability derivativecalculations, directing a trim solution or a time history calculation, storing a list of variables for input or output, directing wind tunnel-type calculations with the aerodynamic model, and storing and printing summaries of a series of trim solutions.

D.2.2 The Aircraft-Specific Program Modules

The aircraft-specific program modules include DERIVS, ERROR, FORCES, SYSEQS, LIFDRG, WTRUN.

D.2.2.1 FORCES

Subroutine FORCES calculates the forces and moments applied to a VSTOL aircraft by aerodynamics, propulsion system, ram drag, Coriolis effects, and reaction control system (RCS).

The FORCES aerodynamics model calcuates contributions for an aircraft with three lifting surfaces - wing, horizontal stabilizing surface, and vertical stabilizing surface - and a fuselage. Each lifting surface can have trailing and leading edge flaps whose effects are modeled with changes in C_m, C_L, and C_D per unit flap and/or control surface deflection whose effects are modeled with a change in angle of attack of the lifting surface per unit control deflection. The FORCES propulsion system can have up to four engines. Each engine has an inlet, thrust vectoring in two directions, and an independent throttle control. The FORCES RCS can have up to ten individually controlled jets located anywhere on the aircraft and oriented in any direction. Each jet can be specified as demand or continuous bleed. FORCES also models the RCS-propulsion system interactions appropriate to continuous and demand bleeding. The FORCES ram drag model provides for changes in ram drag magnitude, direction, and application point as functions of angles of attack and sideslip, airspeed, inlet mass flow rate and aircraft rotation rates. The FORCES Coriolis model provides for changes in forces and moments as functions of mass flow rate through the engine ducts and aircraft rotation rates.

D.2.2.2 SYSEQS

Subroutine SYSEQS contains the equations for the aircraft kinematics, flight control system, actuation system and pseudo-pilot functions.

The aircraft kinematics in SYSEQS use direction cosines to orient aircraft body axes to inertial space; this avoids the singularity at $\theta = 90$ deg. in the standard Euler rate equations. The Euler rate equations are available and integrated in SYSEQS for application as required but are not fed into the kinematics.

The programmed aircraft can be controlled via pitch and yaw thrust deflection, thrust modulation, elevons which combine elevator and aileron functions, rudder, leading edge wing flaps, trailing edge horizontal stabilizer (canard) flaps, and RCS which will accept roll, pitch, yaw, side force and normal force control commands.

Subroutine SYSEQS has two sections of equations. One section, entered by a call to SYSEQS, is used only for trim and derivative calculations. The other section, entered by a call to DEQU, is used during time history calculations and contains most of the differential equations in the simulation. As may be inferred many of the control system statics and control system/actuation interface equations are common to both sections while aircraft kinematics and control system and actuation system dynamics equations appear only in the DEQU section.

D.2.2.3 DERIVS

Subroutine DERIVS generates aircraft body axis stability derivatives about trim. It is called automatically during the trim program option. Changes in body axis forces and moments (X, Y, Z, L, M, N) are calculated for unit changes in the following variables: body axis airspeed components (u_{AS}, v_{AS}, w_{AS}); body axis rotation rates (p, q, r); elevator; aileron; rudder; wing leading edge flap; horizontal stabilizing surface (canard) trailing edge flap; RCS roll, pitch, yaw, normal force, and side force commands; thrust of each engine; pitch thrust deflection; and yaw thrust deflection.

D.2.2.4 ERROR

Subroutine ERROR contains sixteen equations which must be balanced to attain a six DOF trim solution. These equations include balances between applied forces and linear accelerations, applied moments and angular accelerations, inertial and body axis translation accelerations and rates, and Euler angle rates and body axis rotation rates. ERROR also contains user-selected logic for trimming with or without ambient winds. ERROR is called only during trimming. To generate the data required for the sixteen trim balances ERROR calls FORCES and SYSEQS.

D.2.2.5 LIFDRG

Subroutine LIFDRG contains the generalized equations for calculating the lift, drag, moment, and center of pressure shift of the aero lifting surfaces. LIFDRG requires the surface angle of attack, leading and trailing edge flap deflections, and a series of aero constants to perform these calculations.

D.2.2.6 WTRUN

Subroutine WTRUN controls the application of the aerodynamic model equations to generate wind tunnel-type data. Inputs for WTRUN specify the type of independent variable sweep to be run, angle of attack (α) or sideslip (β); initial and final angles in the sweep; and the incremental angle between data points. At each data point, total and component (due to wing, fuselage, horizontal stabilizer, and vertical stabilizer) nondimensional stability axis aero coefficients are calculated and printed out. Initial values may be placed on any variables which appear in the aero model so that dynamic derivatives and aero characteristics as functions of α and β can be generated. For example, Cmq as a function of α might be generated as follows: Run sweeps with pitch rate (q) equal 0.05 or 0.1 rad/sec then calcuate

$$C_{m_q}(\alpha) = \frac{C_m(\alpha)\big|_{q_0 = .05 \text{ or } .1} - C_m(\alpha)\big|_{q_0 = 0.}}{\left[\frac{(.05 \text{ or } .1)\ \bar{c}_w}{2 V_A}\right]}$$

where

$C_m(\alpha)\big|_{q_0} = A$ is the pitch moment coefficient at α with $q_0 = A$

$\bar{c}_w$ = mean aerodynamic chord of the wing

V_A = reference airspeed

D.2.3 Standard Program Modules

The standardized program modules include TRIM, RUNGE, BATAN2, SIMQ, ATMOS, PCACT, and the table lookup and interpolation package.

The OLSIM plotting package is a standardized module which accesses the CALCOMP plotting utilities.

D.2.3.1 TRIM

Subroutine TRIM controls the search for trim conditions. It has a six degrees of freedom trim algorithm based on Newton's method of solving systems of non-linear equations.

D.2.3.2 RUNGE

Subroutine RUNGE controls and applies a 4th order Runge-Kutta algorithm for integration of differential equations during time history runs. Entry point SETUP in RUNGE is called once at the beginning of a time history to initialize all the integrators.

D.2.3.3 BATAN2

BATAN2 is a function subroutine which determines the inverse tangent of Y/X in the range $-\pi \leq \tan^{-1}(Y/X) \leq \pi$. It avoids the problems of infinite or indeterminate operands when X = 0 or X = Y = 0. BATAN2 is a user specified subroutine whose application is demonstrated in the following example:

ANGLE = BATAN2 (Y, X)
where ANGLE = $\tan^{-1}(Y/X)$ in rad

D.2.3.4 SIMQ

Subroutine SIMQ solves a system of linear equations using a Gauss elimination algorith. It is not a user specified module; it is called automatically during trim calcuations.

D.2.3.5 ATMOS

Subroutine ATMOS provides air density, ambient temperature and pressure, temperature and pressure ratios, and speed of sound as function of pressure altitude for standard and tropical day conditions. The atmosphere model is the U.S. Standard Atmosphere.

Input:

ALT = pressure altitude, ft
KATMOS = 1 for standard day, 2 for tropical day

Output:

RHO = air density, slugs/ft^3
TAMB = ambient temprature, deg R

PRESS = ambient pressure, lb/ft^2
TRATIO = temperature ratio
PRATIO = pressure ratio
VSOUND = speed of sound, ft/sec

D.2.3.7 Table Lookup and Interpolation Package

The table lookup and interpolation module contains seven subroutines; STLU, DTLU, INTRP, INTRP2, INTRP4, SEARCH. STLU performs single table lookup and interpolation to determine $y = f(x)$ while DTLU performs double table lookup and interpolation to determine $z = f(x, y)$.

D.3 REFERENCES

D1 Clark, J. W., Jr., Low Speed V/STOL Stability and Control Prediction - Volume I: Model Description and Validation, Report No. NADC-76312-30, 11 January 1977.

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